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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXX.

SESSION 1869-70.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 477.

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ERRATA

In "Studies of Iron Girder Bridges, etc., Vol. xxix."

Page 417,	line	13	from top,		*for* "$\frac{2}{3}$"	*read* "$\frac{3}{2}$."
,, 418,	,,	18	,,	,,	,, "Fig. 2."	,, "Fig. 6."
,, 420,	equ.	11			,, "S^1."	,, "S_1."
,, 429,	line	17	,,	bottom,	,, "$\int_{S^0}^{S}$."	,, "$\int_{S_0}^{S}$."
,, 430.	,,	8	,,	top,	,, "a_x."	,, "at x."
,, 431.	,,	13	,,	bottom,	,, {"Δy^2" in the 7th column,}	,, "y^2."
,, 435,	,,	3	,,	top.	,, "10·749 − 10·668"	,, "10·749+10·668."
,, 441,	,,	18	,,	,,	,, "yl"	,, "y_1."
,, 442,	,,	10	,,	,,	,, ,,	,, ,,
,, ,,	,,	12	,,	,,	,, ,,	,, ,,
,, 444,	,,	3	,,	bottom,	*after* "dilatation,"	*dele* "of the fibres."
,, 449,	,,	23	,,	top,	,, "tons," *for* "at"	*read* "a."
,, 463,	,,	6	,,	,,	*for* "S"	,, "$\pm$ S."
,, ,,	,,	,,	,,	,,	,, "4·5"	,, "$\pm$ 4·5."
,, ,,	,,	7	,,	,,	,, "inch-tons"	,, "foot tons."
,, 464,	,,	4	,,	bottom,	*after* "from O,"	*insert* ", to the left of the first wheel."

,, ,, Equ. 36 is inaccurate, it should be:—

"$$F = \frac{(12\cdot7 - 2\cdot2 + 12\cdot7 - 7\cdot5)\,6}{12\cdot7} + \left\{\frac{1}{2} - 0\cdot08 \times 2\cdot2\right\} = 7\cdot74 \text{ tons}^2.$$"

"2. *Vide*, Rankine, 'Civil Engineering,' art. 160; the quantity within the brackets { }, is the shearing force due to the uniform fixed load of 1 ton, or 0·08 ton per foot run."

,, 465,	Eqns.	38 & 40,	*for* "7·5"	*read* "7·74;"	*and for* "2·19"	*read* "2·27."		
,, 466,	line	1	from top,		*for* "2·19,"	*read* "2·27."		
				also,	,, "0·28,"	,, "0·29."		
,, ,,	,,	2	,,	bottom,	,, "0·8."	,, "0·83."		
,, 467,	,,	16	,,	top,	,, "7·5,"	,, "7·74."		
,, ,,	,,	17	,,	bottom,	,, "71·4."	,, "60·16."		
,, ,,	,,	15	,,	,,	,, "×,"	,, "+."		
,, ,,	,,	10	,,	,,	,, "7·5,"	,, "7·74."		
,, ,,	,,	,,	,,	,,	,, "1·83,"	,, "1·89."		
,, ,,	,,	9	,,	,,	,, "1·83,"	,, "1·89."		
,, ,,	,,	,,	,,	,,	,, "5·49."	,, "5·67."		
,, ,,	,,	7	,,	,,	,, "5·8,"	,, "5·9."		
,, 470,	,,	8	,,	,,	,, "$6 + \frac{5\cdot8}{12\cdot7}$"	,, "$0\cdot5 + 6 \times \frac{5\cdot8}{12\cdot7}$."		
,, ,,	,,	13	,,	top (in some copies),	*for* "$\int^{y_1}$"	*read* "$\int_0^{y_1}$"		
,, 475,	,,	3	,,	top,	*for* "$(2\frac{1}{4} + 8 \times 1)$"	,, "$\frac{2}{3}(2\frac{1}{4} + 8 \times 1)$."		
,, ,,	,,	1	,,	bottom,	*add* "E = 12,000 tons, E_1 = 7,000 tons."			
,, 477,	,,	3	,,	top,	*after* "centre,"	*insert* "of elasticity."		
,, ,,	,,	4	,,	bottom,	,, "inch,"	,, "2" referring to the 2nd footnote."		
,, 480,	,,	4 & 8	,,	,,	*for* "resistance,"	*read* "resisting surface."		
,, 489,	,,	7	,,	,,	,, "O C,"	,, "O X."		
,, 494,	,,	9	,,	top,	,, "$\Delta y\,\Delta x$,"	,, "$\Sigma \cdot \Delta y\,\Delta x \cdot d$."		
,, 495,	,,	3	,,	,,	,, "M,"	,, "M_0."		
,, ,,	,,	16	,,	,,	,, "38·4"	,, "38·7."		

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1869-70.

March 1, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

The following Candidates were balloted for and duly elected:—HORATIO BROTHERS, RICHARD SPELMAN CULLEY, JOHN GWYNNE, ROBERT HANDCOCK, SAMUEL KEEFER, CHARLES MARTIN, B.A., WILLIAM MILLS, JAMES PRICE, EDWARD JAMES REED, C.B., and CLIFFORD WIGRAM, as Members: JOHN GEORGE CRAMPTON, HENRY JAMES GALTON, B.A., HENRY JAMES BURFORD HANCOCK, GEORGE HODSON, HENRY JOLL, WILLIAM GEORGE LAWS, RICHARD LONGLANDS, JOHN MARSHMAN, WILLIAM MORRIS, WILLIAM POWELL, Major FRANCIS IGNACIO RICKARD, Captain FREDERICK SMITH STANTON, R.E., and GEORGE HUNTER TAIT, as Associates.

No. 1,268.—"The Wolf Rock Lighthouse."[1] By JAMES NICHOLAS DOUGLASS, M. Inst. C.E.

BEFORE entering upon a description of the work which forms the subject of this Paper, it is desirable to notice briefly some others which have been, from time to time, executed in its immediate neighbourhood, and with which it is intimately connected.

In consequence of applications, from the foreign and coasting trades navigating the English and St. George's channels, for lights and beacons to mark the dangers of the coast near the Land's End,

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

a lighthouse on the Longships Rock, and beacons on the Wolf and Rundlestone were erected under licence granted to the Honourable Corporation of Trinity House in 1795. In the year 1841, a light-vessel was moored by the same authority off the Sevenstones Rocks, nearly midway between the Land's End and Scilly, in 40 fathoms of water. These were all works of considerable difficulty; and the latter may fairly be considered as the boldest undertaking up to that date with a floating light. The group of rocks included under the name of Longships, lie about 1 mile westward of the Land's End, and $7\frac{3}{4}$ miles N.E. from the Wolf. They are composed partly of killas and partly of granite; the division running through the eastern part of the lighthouse rock, in a north-easterly and south-westerly direction. The Longships lighthouse is a granite structure, from which is exhibited a catoptric fixed light, and it has rendered good service to the mariner; but, owing to the terrific seas to which it is exposed, the lantern, with its centre at an elevation of 79 feet above high water of spring tides, is so much under water during stormy weather, that the character of the light cannot be determined with certainty. It is not considered safe to raise the present tower to a sufficient height to render the lantern free from the heaviest seas; it has therefore been determined to erect in its stead a granite column 110 feet high, surmounted by a first-order dioptric light, and which was commenced last year. The apparatus to be installed therein will admit of an arrangement being carried out for marking by sections of red light the dangers of the Rundlestone Rock and its surrounding shoals to the southward, and the Brissons Rocks to the northward. The Rundlestone lies S. by E. $\frac{3}{4}$ E., at a distance of 4 miles from the Longships, and is $\frac{3}{4}$ of a mile from the shore. It is about 17 feet 9 inches in length, 8 feet 9 inches in breadth at the level of low water of spring tides, and the highest part is 8 feet 3 inches above the same level; but the only available space for the base of a beacon is a portion of the top of the rock, 4 feet 4 inches long by 4 feet broad, at a level of 7 feet above low-water spring tides. The rock, composed of hard grey granite, forms part of a dangerous group of shoals, and is the only portion visible above low water of spring tides. The beacons, referred to as having been erected on the Wolf and the Rundlestone Rocks in 1795, were merely bare poles of wrought iron, about 4 inches in diameter, sunk into the rock and run in with lead. That on the Wolf was about 20 feet in height, and was supported by six wrought-iron stays. The beacon on the Rundlestone was not so high, as stays could not be used, owing to the small size of the rock. Both of these were soon carried away by the sea. In addition to the beacon on the Rundlestone, the position of the rock was indicated by day by two marks of rubble masonry, erected on the land, at a distance of 1 mile.

These are 220½ feet apart, and when brought in line they lead over the centre of the rock. The second beacon placed on the Rundlestone, shown on Plate 4, was designed by the late Mr. James Walker (Past-President Inst. C.E.), the Engineer to the Honourable Corporation of Trinity House. It was erected during the years 1841-3, under the direction of the Author's father, who was Superintending Engineer to the Trinity House. The work was one of great difficulty and danger to those employed, owing to the small dimensions of the rock, and the difficulty of landing, which could only be accomplished at spring tides; and then the sea was seldom smooth enough to admit of a footing on the rock, as a strong tide runs to the westward during the whole of the time that the summit is uncovered. The beacon was designed with a globe 6 feet in diameter; but it fortunately happened that after the mast was fixed, and before the globe could be attached, the most violent storm occurred that had been experienced during the progress of the work, when heavy seas were observed from the shore to completely submerge the top of the mast. The globe was, therefore, with the sanction of the Trinity House, reduced to a diameter of 4 feet 3 inches. The beacon was completed on the 27th June, 1843, and withstood the storms of the succeeding winter; but during a gale in October of the following year, the wrought-iron mast of 6 inches in diameter was broken off at about 2 feet above the socket. In the month of January following, and before any repairs could be effected, a vessel struck the beacon, and carried off the stump and a portion of the cylinder into which the mast had been stepped. The vessel, with a hole in her bottom, fortunately succeeded in getting into the port of Hayle.

During the next summer the beacon was reinstated by the Author's father, in the manner shown on Plate 4, the globe being further reduced to a diameter of 3 feet. Soon after the completion of the work, a vessel was observed to strike the beacon, but without doing it any damage, although several of her timbers were driven in, proving that the blow was not a trifling one. The mast, as thus reinstated, withstood the gales of several winters, but during a storm in 1854 the upper portion of the beacon was carried away; and when an examination could be made, it was found that the cone remained firmly attached to the rock, but that both sides of the connecting flange at the top of the cone-jacket were broken off. In the spring of 1856, the Author was instructed by the late Mr. James Walker, to superintend the reinstatement of the beacon, which he succeeded in completing by the 30th June; but during a severe storm, in the following December, the Rundlestone beacon was once more entirely swept away, the holding-down bolts and mast being broken off at the

surface of the rock. The dangers of the Rundlestone have since been marked by a bell buoy, designed by the Author, and shown on Plate 4. The bell, weighing 3 cwt., is fixed on a wrought-iron stand attached to the deck, and is rung by four long pendulum-clappers, which are Y shaped, and thus have two points of suspension, rendering unnecessary the use of the ordinary guides. The length of swing is limited by india-rubber buffers, attached to the iron plate surrounding the superstructure, and on which the name of the station is painted. The buoy is constructed with a central water-tight compartment, large enough to float it, in the event of a vessel fouling and driving in the outer plating. A second water-tight compartment is formed at the bottom, which is used for water-ballast in cases where the buoy may be required to be placed in shallow water. The weight of the buoy complete is 65 cwt., and its cost about £185. That at the Rundlestone is moored with 32 fathoms of long-link mooring-chain and a 24-cwt. sinker; 16 fathoms of the chain at the lower end is of $1\frac{1}{2}$-inch iron, and the remainder, or upper part, of 1-inch. It is moored in 16 fathoms of water, S.W. $\frac{1}{2}$ W. from the rock, at a distance of $1\frac{1}{2}$ cable, on a rocky bottom and in a strong tideway. It is found to ride well, and to ring efficiently in all states of the weather.

Having thus briefly referred to the previous labours of the Trinity House near the Wolf Rock, the Author proceeds to describe the later and more difficult work which is the subject of this Paper.

The Wolf Rock, shown in plan and section on Plate 3, is situated in latitude 49° 56′ 41″ N., and longitude 5° 48′ 30″ W. From it the Lizard lighthouses bear E.S.E. 23 miles; St. Agnes lighthouse, Scilly, W. by N. $\frac{1}{2}$ N. $20\frac{3}{4}$ miles; Longships lighthouse N.E. $\frac{1}{2}$ N. $7\frac{3}{4}$ miles. The rock is composed of a hard, dark, felspathic porphyry; its highest part is 17 feet above low water of spring tides, which rise 19 feet. The surface is rugged, rendering a landing upon it at all times difficult. The depth of the water close to the rock is about 20 fathoms on all sides, except the S.E., where a shoal extends for a considerable distance, having only $4\frac{1}{2}$ fathoms to 5 fathoms on it at low water at a distance of a cable's length from the Wolf. At a distance of 1 mile from the rock the depth of water on this reef is about 14 fathoms, but in every other direction it is not less than 34 fathoms.

Between the periods of high water and the following low water the tidal stream runs south-easterly, southerly, and south-westerly; whereas from low water to the succeeding high water it sets north-westerly, northerly, and north-easterly. This peculiarity is supposed to extend to a radius of 4 leagues from the rock. Situated as the Wolf Rock is, in deep water, and exposed to the full force of the Atlantic Ocean, a terrific sea falls upon it, as may easily be surmised, and of which there are abundant proofs.

There is reason to suppose, that the question of building a lighthouse on the rock was a subject of discussion between the Admiralty and the late Mr. Robert Stevenson (M. Inst. C.E.), the Engineer to the Commissioners of Northern Lights, as early as the year 1823, as a rough plan exists of a stone structure designed for the purpose, of that date, with an estimate of its requiring fifteen years to build, at a cost of £150,000. The large amount of this estimate was, probably, the reason of the idea being abandoned, and a beacon being proposed instead, which was afterwards erected.

The iron beacon, shown on Plate 4, was designed by the late Mr. James Walker, and was erected during the years 1836 to 1840, under the superintendence of the late Mr. John Thurburn, a pupil of Mr. Walker's.

The difficulties of the undertaking may be estimated from the number of hours actually worked on the rock during each season, which were in:—

1836	39½	hours.
1837	65	,,
1838	85	,,
1839	68½	,,
1840	44½	,,
Total	302½	,,

or 30¼ working days of ten hours each, during the five years. This beacon was executed at a cost of £11,298 4*s.* 1*d.* The mast, which was of selected English oak, 12 inches in diameter, was carried away as early as November of the last-mentioned year. Immediate steps were taken for replacing it by one of wrought-iron, 7⅝ inches in diameter, as shown on Plate 4, but no opportunity occurred for effecting its erection during the following summer. It was, however, carried out, under the superintendence of the Author's father, in August 1842. This mast was bent during the succeeding winter about 3 feet from the perpendicular, the bend being in the direction of the heaviest seas, viz., from the westward to the eastward. During a storm in October, 1844, the mast was again broken off, at about 4 feet above the top of the cone. In July of the following year a second iron mast was fixed, as shown on Plate 4. In this case the mast was increased to 9 inches in diameter, and the globe was reduced to 4 feet in diameter. This mast stood until the early part of 1848, when it was carried away. In August, 1850, another wrought-iron mast, as shown on Plate 4, was fixed. It was 9 inches in diameter at the lower part, and had a globe only 3 feet in diameter. This mast withstood the force of the sea until it was taken down during the progress of the construction of the present lighthouse. The iron work of the beacon, after an

exposure of thirty years to the corrosive action of sea-water, is in a good state of preservation, having been protected by a coat of red-lead paint, renewed annually. Some of the internal cement rubble filling was removed for the purpose of affording space for the stowage of the workmen's tools during the erection of the lighthouse, when the threads of the screw-stays that were embedded in the cement were found to be as perfect as when first made.

The success which had attended the efforts of the Trinity House in the erection of lighthouses on the Bishop Rock, Scilly, the Smalls Rocks, at the entrance of the Bristol Channel, and the Hanois Rock, at the west end of Guernsey, induced the Corporation to undertake the erection of a lighthouse upon the Wolf Rock; and, in the year 1860, the late Mr. James Walker, their Engineer, was instructed to furnish a design for, and an approximate estimate of the cost of, the work. These having been approved, the Author, who was then completing the Smalls lighthouse, was appointed to carry out the work as Resident Engineer. In the autumn of 1861, a site for the workyard was taken at Penzance, 17 miles from the Wolf, and the necessary arrangements were made for commencing operations at the rock in the following spring. It was determined that the craft that had been used at the Smalls lighthouse should be employed at this work, viz., a steam tug of 60 nominal HP., and five barges, each of 40 tons burden, for the conveyance of the stone and other material from the yard to the work. In addition to these, a schooner, of 100 tons register, was built and specially fitted for service as a barrack for the workmen when afloat. Special moorings were laid down for these vessels near the workyard at Penzance, and a timber jetty was erected for loading and unloading them.

The form and dimensions of the tower differ but little from those of the Bishop, the Smalls, and the Hanois. Its exact height is 116 feet $4\frac{3}{4}$ inches, its diameter at the base 41 feet 8 inches, and near the top, at the springing of the curve of the cavetto under the lantern gallery, the diameter is 17 feet. For a height of 39 feet $4\frac{1}{2}$ inches from the base the work is solid, with the exception of a space forming a tank for fresh water. At the level of the entrance door the walls are 7 feet $9\frac{1}{2}$ inches thick, whence they gradually decrease throughout the whole height of the shaft to 2 feet 3 inches at the thinnest part near the top. The shaft of the tower is a concave elliptic frustrum, the generating curve of which has a major axis of 236 feet, and a minor axis of 40 feet. It contains 44,506 cubic feet of granite, weighing about $3{,}296\frac{3}{4}$ tons; and its centre of gravity is 36 feet $2\frac{1}{4}$ inches above the base. In consideration of the exposed position of the work, it was determined to dovetail each face stone vertically and

horizontally, in accordance with the system suggested by the Author's father, and first adopted at the Hanois lighthouse, Guernsey. This method of dovetailing is shown on Plate 1. It consists in having a raised dovetailed band, 3 inches in height, on the top bed and one end joint of each stone. A corresponding dovetailed recess is cut in the bottom bed and end joint of the adjoining stones, with just sufficient clearance for the raised band to enter it freely in setting. From experiments made upon blocks of granite put together in this manner with Portland cement, it is found that the work is so homogeneous as to be as nearly as possible equal in strength to solid granite. This system of dovetailing also affords great protection to both horizontal and vertical joints, against the wash of the sea when the work is first set. The Author is of opinion that by its application, in cases where Portland cement blocks are employed for work exposed to heavy seas, much additional strength would be obtained, and safety during the progress of the work, with probably some reduction in the cost. In addition to the security afforded by the dovetailing, each stone of the first and second courses of masonry is secured to the rock by two yellow metal bolts, 2 inches in diameter, each bolt being sunk 12 inches into the rock, and fox-wedged at each end; a portion of the hole at the top and the bottom being made conical for the purpose. From the 3rd to the 20th courses inclusive, each face stone is secured to the course below by two yellow metal bolts, 2 inches in diameter, and each internal stone by two bolts of galvanized puddled steel, also 2 inches in diameter. Each bolt in these courses is sunk 9 inches into the course below. All the holes for the bolts were bored on the platform in the workyard, and so accurately was this executed, that no instance occurred where the lower part of a hole was found to be out of position for properly inserting and wedging up the bolt at the rock. The masonry, to the level of high-water spring tides, was set in fresh Medina Roman cement, part of which was supplied from the Government Stores at Chatham, and part was manufactured by Messrs. Francis & Co., from which firm the Portland cement was obtained for the work above high water. All the cement used in the work was mixed with an equal portion of clean, sharp granitic sand, obtained from the stamps refuse of the Balleswidden tin mine, near Penzance. This sand is of excellent quality for such work, every grain in it being hard, angular, and rough. Salt water was used for mixing all the cement required for the landing platform and the solid portion of the tower; above this only fresh water was used.

In spite of the precautions taken for the security of the stones in the lower portion of the building, thirty-four stones of the 5th course (which course it was found impossible to complete at the

end of the season of 1865) were carried away during a heavy storm, which raged on the 24th and the 25th of November of that year. It is supposed that the damage was caused by floating wreck, as marks of the cutting of a chain over the edge of the masonry were observed when an inspection could be made of the work. It was also ascertained, soon after the storm, that the ship 'Star of England,' of 1,514 tons register, from Calcutta bound to London, was nearly lost there during the storm, and the vessel, which was said to have been within 100 yards of the rock on the weather side, was only canted clear of it by cutting away her mizenmast. It was, therefore, concluded that this mast with its gear must have driven against the masonry, and caused the damage.

The general internal arrangements and fittings are shown on the section of the tower, Plate 1. The step ladders for ascending from floor to floor, and the partitions between the rooms and staircase, are of cast iron, and the use of wood for the fittings has been limited as much as possible, as a precaution in case of fire. The doors, windows, and storm shutters, are constructed of gun-metal. The windows of the watch or service room, immediately under the lantern, are specially arranged for admitting air to the lantern, and for regulating the ventilation in all ordinary weather. The supply of air is admitted by a valve at the upper part of the window, so as to pass above the head of the light-keeper on duty, and upwards through an iron grating surrounding the lantern floor. The lantern is one of the cylindrical helically-framed type, designed by the Author, and adopted by the Trinity House, a description of which has already been given at the Institution.[1] This lantern was manufactured by Messrs. S. Hodge and Sons, and was exhibited in the Paris Exhibition, 1867; while the curved plate-glass for glazing it and the dioptric apparatus were manufactured by Messrs. Chance Brothers, and Co. The instrument is probably the most perfect for the purpose that has yet been constructed.

With the view of giving the Wolf Light a perfectly distinctive character, a revolving dioptric light of the first order, showing alternate flashes of red and white at half-minute intervals, was resolved upon. This arrangement involved the consideration of the important question, which does not appear to have been previously determined with accuracy, of disposing in each beam the relative proportion of light to allow for the loss in the red beams by passing through a ruby glass medium, and produce at all distances at which the light can be seen, with variable states of the atmosphere, flashes of nearly the same strength. The investigation of the subject was entered into by Professor Tyndall, the scientific adviser of the Trinity House; and as it was one which could not

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 37.

be determined with accuracy by photometric measurements, he, with the Author, paid a visit to the Rock lighthouse, near Liverpool, which has a catoptric revolving light showing one red flash succeeded by two of white at intervals of one minute, and inquiries and observations were made on this light at the Point of Air lighthouse, at a distance of $11\frac{1}{3}$ miles, and at the Great Orme's Head lighthouse, at a distance of $30\frac{1}{2}$ miles.

Experiments with red and white lights were also made at the experimental lighthouse of the Trinity House at Blackwall, and observations on these were taken from a station in Charlton, at a distance of 2 miles. From these practical tests it was determined that the quantity of light to be appropriated to the red beam should be to that of the white in the ratio of 5,275 to 2,250, or as 21 to 9 nearly.

The apparatus has sixteen panels of refractors and lower prisms, and eight panels of upper prisms, to the circle. Eight panels of refractors and lower prisms of 18° each are appropriated to eight beams of white light; and eight panels of refractors and lower prisms of 27° each, together with the eight panels of the upper prisms of 45° each, to eight beams of red light. The colour is produced by ruby glass placed in front of the panels, and revolving with the apparatus. The illuminating power of each beam sent from the apparatus is estimated at 2,250 French units.

A 5-cwt. fog-bell is fixed on the lantern gallery, as shown on Plate 1. It is struck by two hammers worked by machinery fixed in the pedestal of the illuminating apparatus, but independent of that for rotating the latter. For the purpose of giving the signal a distinctive character for the station, the machinery is arranged for striking the bell three blows in quick succession at intervals of fifteen seconds.

In consideration of the great difficulty that would be experienced in landing upon the Wolf, which can only be effected on the north-east side, and even there the surface is rugged and without any vertical face for a boat to approach, it was determined to construct a landing platform, as shown on Plate 3. As the material for this platform could only be landed from boats, small granite ashlar, set in cement, similar to brickwork in old English bond, was adopted. The stones, with the exception of the larger ashlar in the steps and coping, and some rubble-filling obtained from the foundation pit for the tower, are each 24 inches by 12 inches, by 6 inches in thickness, rough pick-dressed, and are laid in fresh Medina Roman cement. Frequent tides, which did not ebb low enough to admit of working at the foundation pit for the tower, were worked at this platform; and so rapidly did this portion of the work progress that the platform was nearly completed before the foundation pit was prepared for setting the first

stone of the tower. The platform greatly facilitated the erection of the lighthouse, and will prove of value hereafter, from the convenience it will afford for landing and embarking at times when it would be impossible to effect this without it. The landing platform contains 14,564 cubic feet of masonry, making together with the tower a total of 59,070 cubic feet, or about 4,375½ tons.

Season of 1861.

The first survey for the purpose of determining the exact position of the proposed tower was made on the 1st July, 1861. The weather had been very unpropitious, and on this, the only opportunity which had occurred for his leaving the Smalls lighthouse, then building, the Author landed upon the rock, and made the best use he could of the short time which the state of the tide allowed; but the sea getting up meanwhile put a stop to his work; and as a boat could not, from the increased swell, approach the rock with safety, he was hauled on board through the surf by a line fastened round his waist. This mode of embarking was frequently resorted to afterwards, for getting the workmen off the rock, when caught by a sudden change of weather and increase of surf.

Season of 1862.

On the 17th March, 1862, the working party got upon the rock, and began to cut out the foundation-pit. The insecurity of the foothold, and the constant breaking of surf over it, rendered great precaution necessary for the safety of the workmen. Heavy iron stanchions were sunk into the rock around the site for the foundation, and each man worked with a safety-rope lying near him, one end of which was attached to the nearest stanchion. An experienced man was always stationed on the summit, as 'crow,' to look out for the sea, who would give warning of such waves as were likely to sweep the rock, when the men would hold on, head to the sea, while it washed over them; picks, hammers and jumpers, some exceeding 20 lbs. in weight, were frequently found to have been washed away, when the waves had passed and were followed by a lull. These circumstances are related, not to magnify the difficulties of the work (which are familiar to many members of the Institution), but in order that attention may be directed to the precautions taken, and to the fact that they were successful in preserving life.

On the 29th September, the last tide of the season was worked. Only twenty-two landings had been effected, and eighty-three hours of work obtained on the rock for the season, although not a single opportunity had been lost when it was possible to work even half an hour. The season was altogether a very unfavourable one for such an undertaking. During these eighty-three hours

considerable progress was made in blasting and cutting out the foundation-pit for the tower, and in the erection of the landing platform.

On the death, in October, 1862, of the late Mr. James Walker, the Engineer to the Trinity House, the Author was appointed by the Elder Brethren to that office; and his brother, Mr. William Douglass (M. Inst. C.E.), who was then completing the Hanois lighthouse, succeeded him as Resident Engineer at the Wolf.

Season of 1863.

The first landing for this year was effected on the 20th February, and the last on the 24th October. During the season thirty-nine landings were effected, and the work on the rock was proceeded with during two hundred and six and a half hours. At its close, the cutting of the foundation-pit and the erection of the landing platform were about half executed, and the dressing of the 6th course of masonry in the workyard was completed.

Season of 1864.

The first landing for this season was effected on the 9th April, and the last on the 5th November. During this year forty-two landings were effected, and two hundred and sixty-seven hours' work obtained on the rock. On the 6th August the first stone of the tower was set. At the close of the season thirty-seven stones of the 1st entire course, or 2nd course of the tower, were set; the landing platform was nearly completed, and the dressing of the 10th course was finished in the workyard. The iron derrick landing-crane, shown on Plate 4, was erected on the end of the landing platform. It has a solid wrought-iron mast, 10 inches in diameter, fixed in a cast-iron well, into which the machinery, when not in use, is lowered by a rack and pinion, and is there secured by strong wrought-iron hinged covers. The wrought-iron derrick, when not in use, is lowered into the long protecting chamber, and is secured therein with strong iron covers.

On Plate 4, the upper and lower deck plans and a longitudinal section of one of the stone barges are given. The lower hold of these barges is fitted with elm rollers, running on iron gudgeons, on which the stones are stowed, in the order in which they are wanted for the work. Each stone, as required to be landed, is rolled on to one of the trucks at the stern of the barge, and is drawn up to the level of the deck by a chain led from the winch on the deck; the chain from the landing-crane is then shackled to the lewis fixed in the stone; the single block of a strong rope veering tackle is also attached to the lewis as shown; one end of this tackle is secured to one of the windlass bitts, and the other end to a break-

barrel on the winch. As the chain of the landing-crane draws the stone from the truck over the roller at the stern of the barge, with the heave of the vessel, the veering-tackle is eased away by the break, and the tackle is kept just sufficiently taut to prevent the stone being driven by the sea against the rock. Blocks of stone have frequently been landed, without damage, in this manner, with a rise and fall of wave of 12 feet.

The relative positions of the mooring buoys, barges, and landing boat, when engaged at the rock, are shown on Plate 3. Each barge, when at the landing-crane, was moored as shown, stem and stern, with 10-inch coir hawsers; and the stern hawsers even of this size, which being shorter than those at each bow, had not so much to give and take, were frequently parted. The barrack schooner, for the accommodation of the Resident Engineer, his assistants and working party, was moored E.N.E. from the rock, at a distance of $\frac{3}{4}$ mile, and remained there as long as there was an opportunity of doing any work. When this was no longer possible, and there was no immediate prospect of better weather, the moorings were slipped, and the vessel was taken to Penzance, there to await another opportunity.

A perspective view, with plan and sections of the landing boat used for the work, is shown on Plate 4. This boat, which is admirably adapted for the purpose, is built diagonally, of two $\frac{5}{8}$-inch thicknesses of elm plank, without timbers or floors, and is provided with a landing-deck and mast forward. The deck and gunwale forward are covered with rough rope-matting, for the purpose of affording a good foothold in jumping from or into the boat. Each workman was provided with a cork life-belt, which he was compelled to wear while landing on or embarking from the rock; and it was frequently necessary, for the safety of the men, that they should wear these belts during the whole of the time that they were engaged upon the rock.

The moorings laid near the rock for the vessels were as follows: Those for the sailing barrack vessel were laid about $\frac{3}{4}$ mile E.N.E. from the rock, in a depth of 36 fathoms, on a bottom composed of coarse sand and shells. The moorings consisted of a 30-cwt. mushroom anchor, 90 fathoms of $1\frac{1}{8}$ inch chain (with a swivel and riveted shackle at every 15 fathoms), and an iron spherical mooring buoy, $5\frac{1}{2}$ feet in diameter. As it was necessary that the vessel should be securely attached to the mooring, and yet be free to slip from it readily under canvas, in such a manner as to avoid drifting on the rock, the following method was adopted: A piece of chain, of the same size as the mooring chain, and about 3 fathoms in length, was shackled to the mooring chain at 3 fathoms from the buoy. To the upper end of this chain was shackled about the same length of $\frac{1}{2}$ inch chain, and the end was carefully stopped to

a mooring ring at the crown of the buoy. In mooring the vessel, the end of the small chain was detached from the buoy, and was passed over an iron roller at the bow, and twice round the windlass. The end of the mooring chain, when hove in, was stopped to a strong eye-bolt in the deck abaft the windlass; the end of the small chain was then passed back over the windlass and roller at the bow, and secured in the same manner as before to the buoy, which was hoisted on to the bow of the vessel, and there lashed. When it was necessary to slip from the moorings, the buoy was first thrown overboard, and then the chain was slipped from the windlass, the whole operation being easily performed in one minute.

Each of the three moorings close to the rock, for securing the stone barges, was laid in about 25 fathoms water; each mooring consisted of two 24-cwt. cast-iron sinkers, 30 fathoms of $1\frac{1}{4}$ inch ground chain, and 15 fathoms of 1 inch upper chain, to which was shackled a $5\frac{1}{2}$ foot iron spherical mooring buoy, with a strong mooring eye at the crown, to which the craft was secured. These moorings, laid on a rough, rocky bottom, in a strong tideway, and with a continuous swell, were subject to great wear, especially the portion on the ground. They were usually laid between the latter part of February and the early part of March of each season, and were taken up between the latter part of October and the early part of November. It was generally found that the iron in the chain was reduced in diameter during the above period nearly as follows, viz., from the buoy to 20 fathoms $\frac{3}{32}$nds of an inch; this portion of the chain, where the links were not in contact, being coated with short seaweed and crustacea. From 20 fathoms to 30 fathoms the chain was quite bright, and nearly uniformly reduced in diameter $\frac{1}{4}$ inch. From 30 fathoms to the sinkers (45 fathoms), the chain was rather bright, and reduced about $\frac{1}{8}$th of an inch. No shackle, even with its pin well riveted in when hot, could be trusted in the part of the chain where the greatest wear occurred; the incessant hammering on the rock soon loosened the pin, and rendered it unsafe. All the mooring chains used were long linked, and without studs. Each mooring was lifted and carefully examined once or twice during the season as opportunity offered; and when taken up at the end of each season, they were thoroughly overhauled, and the worn parts cut out and replaced by new.

Season of 1865.

The first landing for the season was effected on the 11th April, and the last on the 17th December. Between these dates forty-one landings were effected, and the work on the rock was carried on for two hundred and fifty hours. At the close of the season the 4th course was completed, and thirty-four stones were set in the

5th course. In the workyard the dressing of the 18th course was completed. It was fully expected that the 5th course would have been completed at the rock before the works were closed for the winter; but the state of the weather rendered this impossible, and those stones which were set, thirty-four in number, were carried away, as previously stated, during a severe storm in November.

Season of 1866.

The first landing for the season was effected on the 5th March, and the last on the 13th October. During the summer thirty-one landings were effected, and two hundred and twenty-four hours and a half worked on the rock. At the close of the season, the 9th course of the tower was completed, and ten stones were set in the 10th course. In the workyard the dressing of the 26th course was finished.

During this season the wrought-iron setting crane, shown on Plate 4, was erected on the tower, and used for setting the work. At the close of the season, the bare post of this crane—a wrought-iron cylinder 16 inches in diameter, and the metal of which was $1\frac{1}{4}$ inch in thickness,—was left in position standing 20 feet above the masonry, and 23 feet above high water of spring tides; but during the winter it was broken off flush with the surface of the work. When an examination was made of the material at the fracture, it was found to be of excellent quality.

Season of 1867.

No opportunity occurred for landing on the rock until the 6th May, and the last for the season was on the 5th November. During this time forty landings were effected, and three hundred and thirteen and a half hours worked on the rock. At the close of the season, the 23rd course was completed, and eight stones were set in the 24th course. In the workyard, the dressing of the 39th course was completed. At the commencement of this season's operations at the rock, a new mast for the setting crane was fixed; a top mast was also fitted to it, and the hoisting and setting of this portion of the work was carried out as shown on Plate 4. On the 13th of June, the sea very smooth, all hands were able to remain on the rock for the first time over high water, on the top of the 11th course.

Season of 1868.

Between the first landing, on the 31st March, and the last, on the 14th October, thirty landings were effected, and two hundred and seventy-six and a third hours worked on the rock. At the close of the season, the 47th course of the tower was completed, and in the workyard the dressing of the masonry was finished.

On the 17th and the 18th of June, the steam winch, with boiler, shown on Plate 4, having a pair of 8-inch cylinders, and 12-inch stroke, was fixed, and on the 29th was used for the first time; this was doubtless the first occasion of the employment of a steam engine upon a tidal rock. It worked successfully to the completion of the tower, and considerably facilitated the process of construction. The average time occupied in raising each block of stone from the landing platform to the top of the work was only two and a half minutes, while to perform the same duty by manual labour would have required fifteen minutes.

Season of 1869.

The first landing for the season was effected on the 16th March, and on the 19th July the last stone of the tower was laid by Sir Frederick Arrow, the Deputy Master of the Trinity House. To this date there had been twenty-one landings, and one hundred and ninety-four and a half hours of work on the rock, making a total for the eight working seasons of two hundred and sixty-six landings, and eighteen hundred and nine and a half hours, or nearly one hundred and one working days, of ten hours each, for the erection of the tower.

Since the completion of the tower, the heaviest seas that have been experienced were on the 11th September, during a violent gale from the westward, when large quantities of water went over the tower; but the residents state that although the shock was distinctly felt with each wave stroke, scarcely any tremor was perceptible.

The light was first exhibited on the 1st of January, 1870, and has since been continued with regularity every night from sunset to sunrise. Before the light could be shown, the services of Mr. W. Douglass, the Resident Engineer, were required for the erection of a similar work on the Great Basses Rock, off the south-east coast of Ceylon; the charge of the completion of the Wolf was, therefore, intrusted to Mr. M. Beazeley (M. Inst. C. E.), the Assistant-Engineer at the work, who is also proceeding with the erection of the Longships lighthouse.

It is a source of thankfulness to the Author to be able to state, that this difficult and dangerous work has been brought to a successful termination without loss of life or limb to any person employed. This success is mainly due to the steady perseverance of the Resident Engineer, his assistants, and their workmen; and the Author would desire to record the personal interest and willing heartiness exhibited by those employed upon this and similar works that have been carried out by the Trinity House.

As this is a matter of the utmost importance, affecting as it does the success of similar undertakings, a somewhat detailed account of the system under which the workmen are employed may not be con-

sidered uninteresting. Each workman is engaged at a daily rate of wages at the commencement of each year, and signs an agreement for one year; the wages are paid monthly, from which is deducted a sum equal to twopence per day as a reserve until the end of the season, which reserve is forfeited in the event of the man's leaving the employment without giving a month's notice. When at sea an allowance of 25 per cent. is added to the ordinary wages, and as a further encouragement for good conduct and perseverance, a gratuity of 6*d.* is allowed for every hour worked upon the rock. This gratuity is not payable, however, in the case of misconduct, or in the event of the man leaving the employment during the working season. The sum of 1*d.* per day is deducted from the wages of each workman for a Sick and Accidental Insurance Fund, which is managed by a committee of four of the workmen, elected by the whole of the subscribers, the Resident Engineer acting as treasurer.

In case of sickness, or accident, each subscriber is paid 2*s.* per day, and is provided with a medical attendant. At the close of the work a balance of £48 8*s.* 8½*d.* remained in the hands of the treasurer, which was distributed amongst six persons connected with the works, viz., two who were then on the sick list, three who had met with accidents on the works, and the widow of a workman who had recently died.

The total cost of the undertaking, including lantern, illuminating apparatus, cost of workyard, vessels, and all incidental expenses, may be taken at £62,726. This cost, considering the exceptional difficulties of the work, compares favourably with any similar work that has yet been executed.

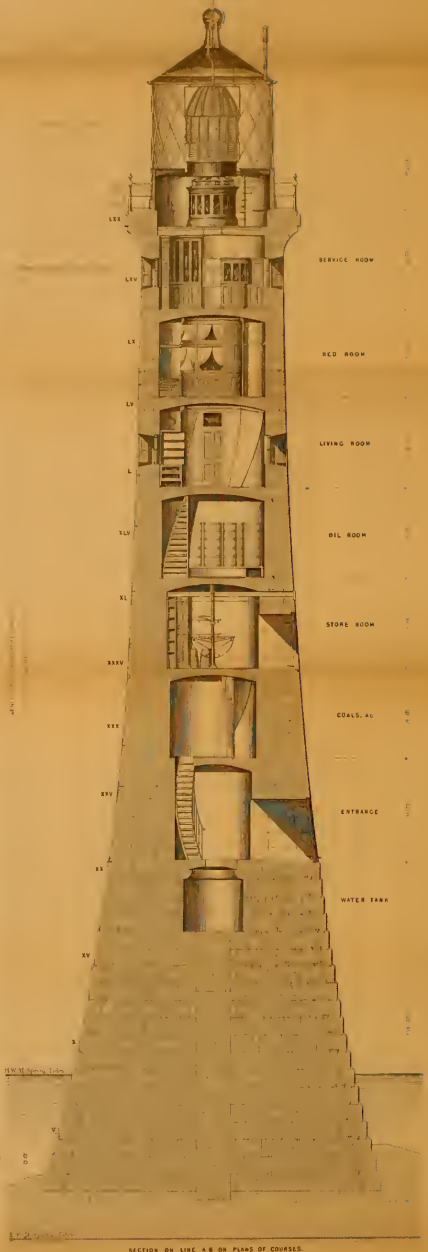
The average number of persons of the various classes employed at the Wolf Lighthouse was as follows, viz.:—

1	resident Engineer.	2	Engineers of steam-tug.
1	assistant ,,	2	firemen of ,,
1	clerk.	1	millwright.
1	storekeeper.	22	masons.
1	foreman mason.	6	carpenters and shipwrights.
1	master of steam-tug.	6	smiths.
1	mate of ,,	14	seamen.
1	master of sailing-tender.	2	miners.
1	mate of ,,	6	labourers.
9		Total 70	

The communication is accompanied by a series of diagrams, as well as by a number of reduced drawings, from which Plates 1, 2, 3, and 4 have been engraved.

[Sir Frederick Arrow

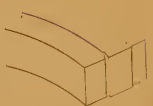
GALLERY LANTERN AND ILLUMINATING APPARATUS, AT LEVEL OF SERVICE STAGE



SECTION ON LINE A B OF PLANS OF COURSES.

THE WOLF ROCK LIGHTHOUSE.

PLANS OF COURSES



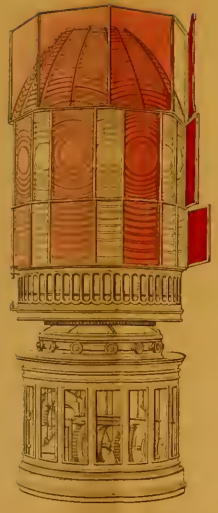
VIEW OF STONE

SECTION A B

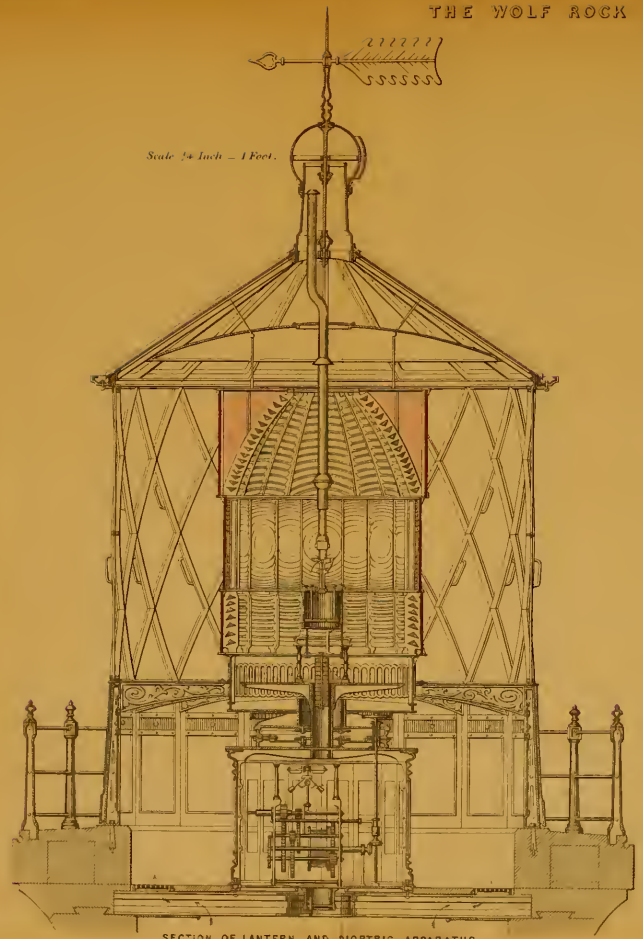
A B
PLAN

DETAILS OF DOVETAILING

THE WOLF ROCK LIGHTHOUSE.



VIEW OF DIOPTRIC APPARATUS.

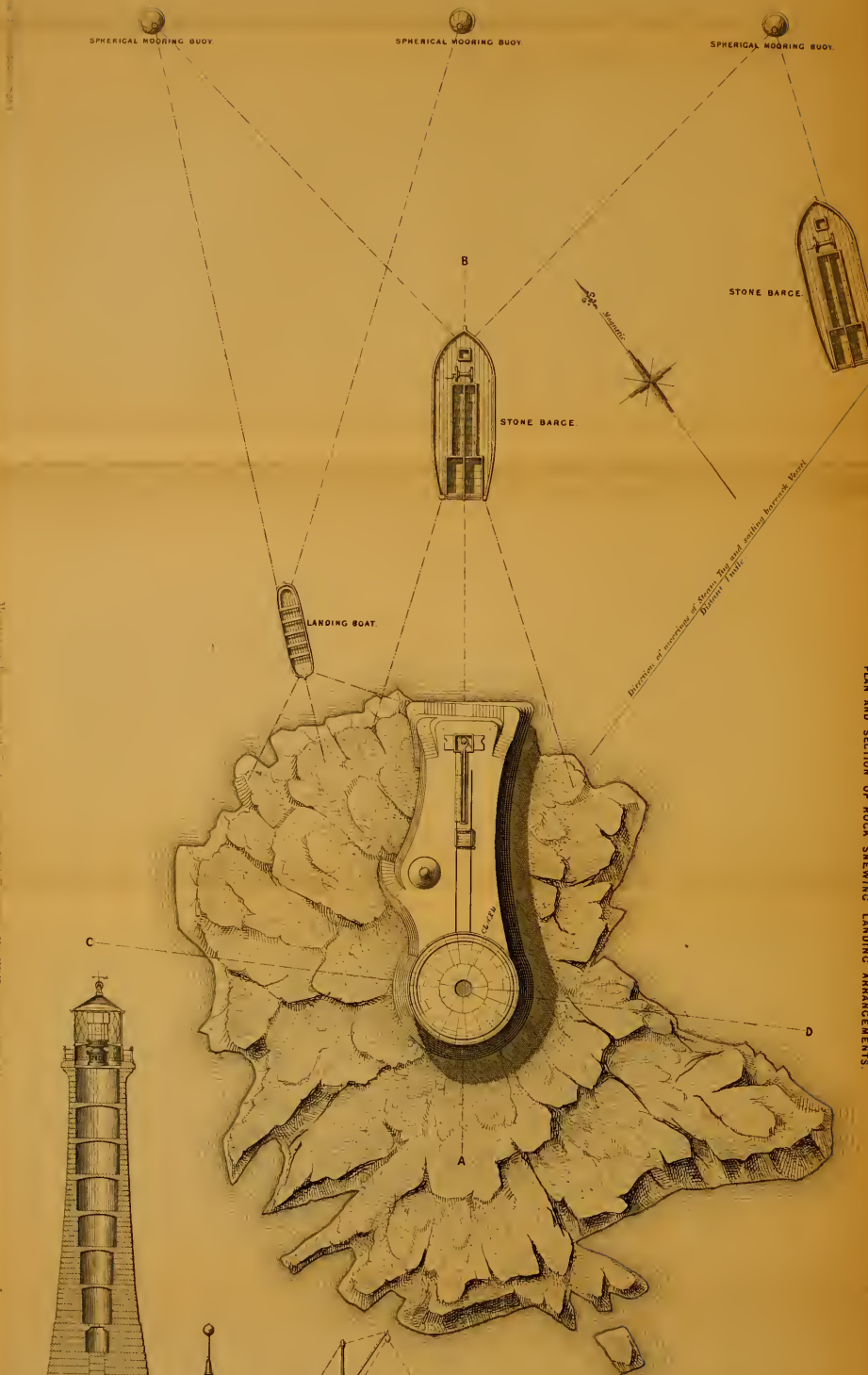


SECTION OF LANTERN AND DIOPTRIC APPARATUS.

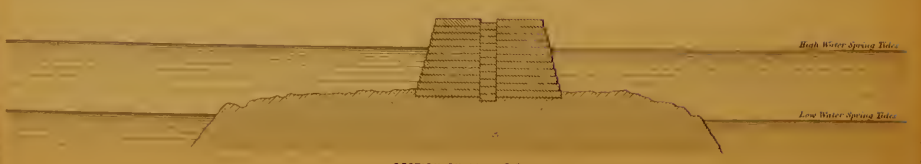
CHART SHEWING WOLF AND NEICHBOURINC LICHTS.

THE WOLF ROCK LIGHTHOUSE.

PLAN AND SECTION OF ROCK SHEWING LANDING ARRANGEMENTS.



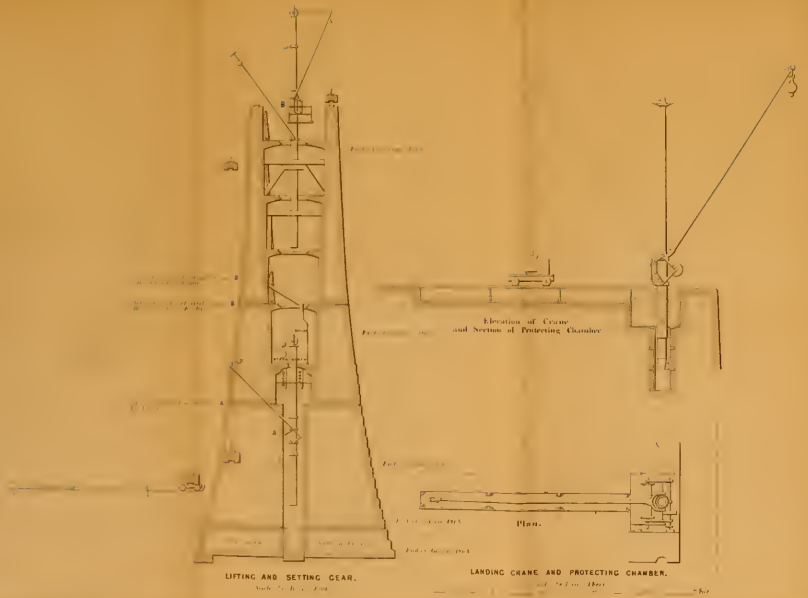
SECTION ON LINE A B ON PLAN.



SECTION ON LINE C D ON PLAN.

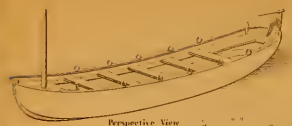
Scale of Feet.

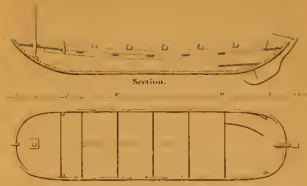
PLATE. 3



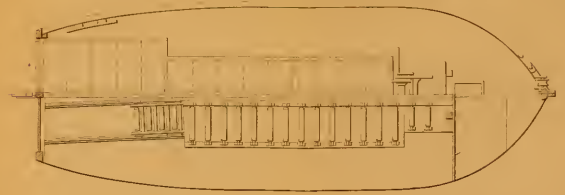
LIFTING AND SETTING GEAR.

LANDING CRANE AND PROTECTING CHAMBER.

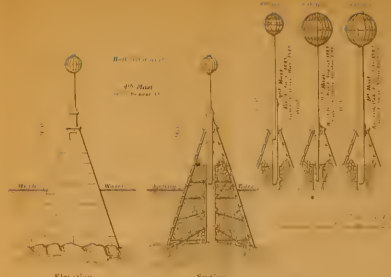




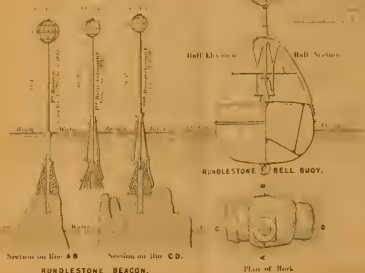
LANDING BOAT.



STONE BARGE.



WOLF BEACON.



RUNDLESTONE BELL BUOY.

RUNDLESTONE BEACON.

Sir Frederick Arrow said, although familiar with the details of the work, he was struck, as the Paper was being read, with the mention of the late Mr. Robert Stevenson (M. Inst. C.E.) in connection with the undertaking, and the time that Engineer estimated it would take to build a lighthouse on the Wolf Rock, and the sum it would cost. Great progress had been made in engineering science in the interval. It was not that Mr. Stevenson was under the mark; but that the progress of engineering, and the intelligence that pervaded all classes of Engineers, had enabled the work now to be brought to a practical success, at a much less outlay of time and of money. That it had been so was a source of thankfulness, not only to the Elder Brethren of the Trinity House, but to the community who paid for these lighthouses, which were a great boon to trade and commerce, and a blessing to humanity. The Wolf Rock, which was only uncovered for a short time during every tide, was until a few months ago the dread of the mariner, and, as a seaman, he had passed many an anxious night in its vicinity, thinking of the danger, and seeking to avoid it; but in taking a ship past it now, he should seek the path of safety, which the lighthouse afforded. Great personal as well as moral courage had been displayed in carrying out this work, which was so beset with difficulties and dangers, that the people engaged upon it might be said frequently to have carried their lives in their hands.

Mr. Vignoles, President, took the opportunity of observing, on the similarity of names, that the Robert Stevenson alluded to in the Paper was the late Engineer of the Commissioners of Northern Lights, and not Robert Stephenson the railway Engineer. It was only due to Mr. Robert Stevenson, whose great work was seen in the Bell Rock lighthouse, and to his sons who were successfully following the same path, that this distinction should be made, inasmuch as some of the younger members of the Institution might not be aware of it.

Mr. W. Parkes congratulated Mr. Douglass on having completed this important work. The Paper was one of a class which gave but little field for discussion. There was nothing in the design which called for criticism. The original type, the Edystone, had, in all cases of rock lighthouses, been followed with comparatively little variation; and the improvements effected had generally been from the greater facilities of carrying out the work; for instance, Mr. Douglass had spoken of the employment of steam, and he thought there were some improvements in the methods of landing the stones since Smeaton's time, which seemed to have been exceedingly complete in this case. It was only on studying the Paper, that the merits of this work could be thoroughly appreciated. It was in the perseverance from day to day, and in watching every opportunity, even with risk to life, to get a few hours' work at a time

on the rock. The little he had himself done in this way was not to be compared with the dangers and difficulties which the Author and his assistants had contended with. With regard to the details of construction, he would ask Mr. Douglass whether, with the excellent material now obtainable, it might not be possible to reduce the work in the most difficult part, viz., in preparing the foundation? He thought time would be saved if a bed were cut for the outside ring of stones only, instead of over the whole area of 40 feet in diameter, and if the interior was levelled up with rubble work, in Roman or other quick-setting cement. Considerable advance had been made since Smeaton's time in the manufacture of cement. No doubt the mortar which was used at the Edystone was first-rate of its kind, though far inferior to the cement of the present day. In works exposed to the force of the sea, Portland cement when once set was almost as good as stone itself. At Dover and at other places, where fine granite masonry was used, the granite had separated rather than the cement. The dovetailing system was originally introduced by Smeaton, but then he had only hydraulic lime mortar, which, though good of its kind, was comparatively slow-setting. It appeared that a course of stones in this work was carried away by a heavy storm, but there was evidence of wreck having struck it. Would it be possible for the sea itself, without the assistance of wreck, to carry away a course, or part of a course, of stones solidly set in Portland cement? He thought not, and that it would be like the solid rock itself. The cutting of the stones into complicated shapes must be a source of considerable expense, and although the cutting was done on shore it must, he thought, involve some complication in the setting of the work, and he would ask the Author to state his opinion upon the real advantage of that from his own experience. Mr. Parkes was satisfied that, in any position where the work was exposed to the action of the waves, a stone tower was the only kind of structure that ought to be attempted. He believed every cast-iron lighthouse so exposed had been more or less a failure. The first was the Bishop, which was washed away: a stone tower was substituted, and it stood. Then there was the Great Basses lighthouse, on which Mr. Douglass' brother was now employed. In that an amount of money was spent in cutting the foundation and erecting a flagstaff equal to the whole cost of the Wolf Rock lighthouse; and the difficulty was enhanced by the great amount of work required in cutting the foundations for the cast-iron plate lighthouse. That could not be said to be a failure, however, of the structure itself, because the original design was never carried out. In the case of the Roman Rock lighthouse, in Simon's Bay, Cape of Good Hope, three years were occupied in preparing the foundation on the rock, and the lighthouse was erected in a short time;

but a few weeks after completion it cracked, and had to be patched up.[1] He was not aware of any other case in which iron lighthouses had been commenced under the wash of the waves. Although all the stone lighthouses had succeeded admirably, he thought the adoption of them might be carried too far; and that for Engineers to adopt this plan of lighthouse, in positions free from danger from the sea, when a different structure might be erected to answer all the purposes in much less time and at much less cost, was an evidence of some want of original resources.

Mr. Gregory, Past-President, said that although there might be few who were in a position to criticise the Paper, or enter into the discussion of it, still all must admire the perseverance and the ability displayed in carrying out the work. The great element of success in such a work was, as recorded by Smeaton in his celebrated "Narrative," the overcoming of difficulties which presented themselves day by day, and which occupied and absorbed the brain and life of the Engineer; while at the same time they give very little note of their existence, and could only be thoroughly known by those who had sustained such labours themselves. Having, in conjunction with other members of the Institution, been appointed a juror at the Paris Exhibition of 1867, he might remark that the two branches of construction in which English Civil Engineers chiefly distinguished themselves were in machines for the destruction of their kind—great guns and materials of warfare—and in appliances for saving life, and especially in lighthouse structures and apparatus, to which the Trinity House so largely contributed. He might add that the French Engineers, who had thoroughly mastered this subject, expressed great admiration at the Exhibition of lighthouse apparatus, which illustrated the position of that science in Great Britain, and bore testimony to the perfection of the works carried out by the Trinity House under the direction of such men as Sir Frederick Arrow, the Deputy Master and the other Elder Brethren, and under such practical Engineers as the Author of this Paper.

Dr. W. Pole, while bearing his tribute of admiration, both to the work and to the Paper, would only make a remark or two on an incidental point, namely, the arrangement for signalling during the prevalence of fogs. The provision here, as in most other cases, was by means of a bell, struck at intervals; but a bell was not very powerful for the purpose; he believed its sound was less penetrating in a foggy than in a clear atmosphere, and vessels might come into dangerous proximity with a rock without either seeing the light or hearing the bell. The subject was an important one,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 19.

and it had been long under the consideration of the Corporation of the Trinity House. He had lately had an opportunity of inspecting a new apparatus erected at the St. Catherine's lighthouse in the Isle of Wight, and probably some account of it might be interesting. The instrument was, he believed, an American invention, and consisted of a large metal horn blown by compressed air, and giving a very powerful piercing tone. The sound was produced, however, not on the principle of the ordinary horn or trumpet, but on that of the clarionet, or the brilliant trumpet pipes of an organ. The tone in these was due to what was called a reed—a thin tongue of elastic material, placed so as to cover a long opening, or slit, leading into the pipe of the instrument. The reed was fixed at one end, the part over the opening being left free to vibrate. When it was attempted to drive a current of air into the tube through the slit covered with the reed, the latter, by its flexibility and elasticity, alternately covered the opening and left it again, allowing a jet of air to enter the tube every time the opening was left free. By this action the reed was set in quick vibrations, and the puffs of entering air, following each other in regular succession, and with great rapidity, gave rise, on well-known acoustical principles, to a musical tone. The fog-horn was on this construction, but with all its parts magnified to colossal dimensions. The reed, instead of being, as in the clarionet, a thin strip of wood, or, as in the pipes of an organ, a small leaf of brass, was here a thick plate of hard steel 5 inches long, 2 inches wide, and $\frac{1}{4}$ of an inch thick at the root, tapering to $\frac{1}{8}$th of an inch at the loose end. This was enclosed in a box, communicating with the reservoir of compressed air. The air, after passing through the opening over which the reed was placed, entered the main tube of the horn, which was of brass, 8 feet or 10 feet long, gradually expanding in diameter till it finished in a bell-mouth 2 feet wide. The tube was placed vertically, and passed through the roof of the building, its upper part being bent into an elbow, so as to make the bell part horizontal, delivering its sound straight out to sea. The pressure of air required to sound the horn was from 5 lbs. to 10 lbs. per square inch. In the apparatus Dr. Pole saw, it was compressed by a hot-air engine, also of American contrivance; but this seemed to him clumsy and complicated, troublesome to manage, and possibly not altogether trustworthy; and he would venture to suggest to the authorities of the Trinity House, whether a small steam engine would not be much simpler, and more to be depended on. As the headland where this apparatus was erected stood well out in the Channel, it was necessary to extend the signals over the whole southern semicircle from east to west. To enable the horn to cover this large extent of arc, it was made to revolve slowly, so as to

present its bell successively in all directions, and so to deliver its warning to all parts of the sea within its range. The sound was not continuous, but was interrupted, at intervals, like a flashing light; and it was evident that, by varying the intervals, such signals might be made to give varying indications, so as to identify the places they proceeded from, an application, in fact, of the general principle of revolving lights. The revolution of the horn, and the alternate admission of air to, and exclusion from, the pipe, were regulated by machinery actuated by the engine. The tone was very loud when heard in the line of the bell, and he believed it had peculiar power in piercing the fog; it was heard out to sea for many miles' distance. He thought, on the whole, it was a very ingenious arrangement, and if experience proved it to be effective, it would no doubt be exceedingly useful in a climate so liable to mists as that of the British Islands.

Captain Owen said, having been acquainted with all Mr. Douglass' proceedings in connection with lighthouses, and with those of Mr. Douglass, sen., he was struck with the modest way in which these proceedings had been narrated by the Author. If young Engineers wanted to obtain Mr. Douglass' qualifications they must do as he had done; he knew how to take a tool out of a workman's hand and to do the work himself. Mr. Douglass was not only an Engineer, but he was a blacksmith, a carpenter, and a mason in his own person, as well as a seaman. Captain Owen was personally interested in the building of the Bishop and the Wolf Rock lighthouses, and only such men could make any progress in works of this kind, and carry them out to completion.

Mr. G. R. Stephenson said he had passed the Wolf Rock many times under great trepidation, and felt much satisfaction at the completion of the lighthouse, though he was not prepared to discuss the details of it; if indeed there was anything to discuss in the admirable way in which the proceedings had been conducted from the commencement to the completion. He knew of no site or position for a lighthouse which required more skill, or involved more difficulties and dangers, than was the case with the Wolf Rock structure. He regarded its erection as one of the greatest boons to the commerce of the country. It would be the means of saving thousands of pounds' worth of property in a year, besides human lives. Instead of that spot being shunned, it would now be anxiously sought for, as one of the best landmarks that could be obtained. He had made the Channel when he had not been able to take any previous observations for five or six days, and was obliged to run up at hazard. If this lighthouse had been there, he should have sought it, and having found it, he would have been sure of a safe run up Channel. He would only add that the Robert Stevenson mentioned in the Paper was not his relative;

but he was as distinguished in the works he had executed in lighthouses as his relative had been in other branches of engineering.

Mr. Redman said, in the year 1840 he was engaged by the late Mr. Walker (Past-President, Inst. C.E.), for the Corporation of the Trinity House, in making a survey of the Tuskar Rock in the Bristol Channel, and on that occasion he made the acquaintance of the Author of this Paper and of his father. The Tuskar Rock presented great difficulties; there was a rapid tideway, and the most prominent and salient points barely reached half-tide level. An area of 120 acres of carboniferous limestone was exposed for a short time, and a beacon was subsequently erected on it somewhat of the character of the Wolf Rock beacon; but it was supported by stays, in the same way as the mast of a ship was sustained by the standing rigging. That beacon was now in its original condition. After waiting for a fortnight, he determined to start one morning, contrary to the advice of the elder Mr. Douglass, to commence the survey, but he was unable to land on the rock. During the subsequent spring tides, he completed the survey and made a report in reference to the beacon. To show the hazard attending works of this kind, he might mention that, on the occasion of the Elder Brethren of the Trinity House visiting another work in that district at about that period, the boat in which they were conveyed capsized, and three of the number were drowned. As there was no opportunity of strengthening the Wolf Rock beacon by the addition of stays, the mast was broken off, and several succeeding ones had failed.

A somewhat similar plan was resorted to, in preparing the foundation of the Wolf Rock lighthouse, as had been followed in preceding structures of this form, of which the Edystone might be taken as the type, and no greater tribute to the talent of Smeaton could be paid. The use of cement or concrete for obtaining level steps might be applicable to many sites, but the dense nature of the porphyritic mass supporting a granite column rendered the intervention of a foreign medium hazardous. In a case of this kind, too great care could not be taken in dovetailing the courses, and the additional cost thus incurred, when spread over the total cost of the lighthouse, must be so slight as to warrant the precautions judiciously observed by the Author. For the base of the lighthouse a system had been followed, which was originated, he believed, by Mr. Walker, and was first adopted in the case of the lighthouse at the entrance of the Menai Straits. In that instance curved faces were replaced by offsets at the base of the tower. He believed Mr. Walker considered they had the effect of breaking up the waves, and checking their tendency to shoot up the face of the tower. Perhaps the only defect in the Edystone was the want of altitude; and in a heavy gale the light was almost submerged by the water

running up the tower.[1] That had been prevented in succeeding lighthouses by the greater altitude of the tower.

A simpler form of dovetailing had been employed in the Skerryvore, the Bell Rock, and the Menai lighthouses, viz., that of plain joints radiating from the centre, with the courses joggled to those below, and a cube of harder material, as slate, inserted diagonally in the joints. When an entire ring was set in that way, the system was as perfect as any other with which he was acquainted. The courses adopted by Smeaton were a complete Chinese puzzle; no one stone could be taken out without affecting all around it; and Smeaton was not content with dovetailing the external ring, but every succeeding ring was most ingeniously dovetailed. The total cost of the Wolf Rock lighthouse contrasted favourably with that of other lighthouses of a similar character. The Skerryvore had been referred to by a parliamentary committee as entailing a vast outlay for a single light; but the mass of the Skerryvore was about three times the mass of the Edystone, and the height of the tower was 158 feet, while that of the Edystone was only 90 feet.

With reference to the saving of life by the establishment of lights, it was an acknowledged fact that, prior to the lighting of the Western or Scilly Isles, the number of wrecks was quadruple what they had been subsequently, though the tonnage was only about one-fourth what it was at the present day. It was a curious fact that there were other Wolf Rocks in the islands of the North Atlantic, on the east coast of Labrador, in the Gulf of St. Lawrence, and in the North Pacific—all no doubt deriving their name from the terror inspired by their position.[2] He trusted that this work

[1] *Vide* a large engraving, with the sea breaking over the lantern, "The Edystone lighthouse *during* the storm, 22nd and 23rd November, 1824," painted and engraved by Wm. Daniell, R.A., 6th July, 1825.—J. B. R.

[2] A reference to the list of authorities will show how the nomenclature has oscillated :

Yulf (Sax.), Yulf, Wolf.		
Sea Mirrour, Amsterdam,	"Wolf"	A.D. 1658
De Wit's Atlas, Ditto,	"The Gulfe"	1688
Le Neptune François, Ditto,	"Le Loup"	1692
Ditto, English Channel,	"Let housen de Wolf"	1693
Edmund Halley, English Channel,	"Gulf"	1701
Joannes Van Keulen, Ditto, Amsterdam,	Ditto	1751
Borlase, Islands of Scilly, pp. 1 and 2,	"Gulph" or "Wolf"	1756
Greenville Collins,	"Gulfe"	1760
Chart No. 13a.—"Neptune," L'An VI. de la République, Paris,	"Gulf ou Wolf"	
7.—Ditto, "Mers du Nord," Paris, Depôt de la Marine,	"Gulf Roche"	1776
42.—Ditto, English Channel,	"Wolf Rock or le Loup"	1798-1802
46.—Ditto, Land's End, "Des Sorlinges," Depôt Genl. de la Marine, 1825, Lt. Mackenzie,	"Wolf Rock"	1792

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might redound as much to the credit and the future prosperity of those connected with it as the Edystone had done to Smeaton.

Mr. J. Coode observed that Dr. Pole had referred to a remarkable instrument, introduced for the purpose of signalling during fogs. Believing as he did that the instrument was destined to work an entire revolution in fog signalling, he thought it was only right that the name of the inventor, Mr. Daboll, an American, should be put upon record. With respect to the volume of sea thrown over the Edystone during heavy weather, he might remark that the greatest obscuration of the light did not occur at the height of a gale, but afterwards, when the great rollers ran over the sloping back of the rock and up the lighthouse; the vignette in Smeaton's Narrative was not in the slightest degree an exaggeration of what happened on such occasions.

He could not assent to the statement that Portland cement was a material which, in works exposed to the wash of the sea, was as strong as the stone itself. That remark must be received with considerable qualification. At the end of a month or three months it might approximately possess the strength of stone, but prior to that it did not. It was difficult to get at the same time a quick-setting and a very strong cement. Some time ago he imported a cargo of foreign cement, the only one of the kind, he believed, that had been brought to this country. It was obtained from a little seaport called Zumaya, on the north-east of Spain, about 20 miles west of San Sebastian. Its strength, combined with quick-setting properties, was remarkable. By experiment he ascertained that, at the end of eight hours, the usual test brick of $2\frac{1}{2}$ superficial inches bore a tensile strain of 177 lbs., while Portland cement gauged at the same time sustained only 91 lbs.; in the same way, at the end of twenty-four hours, it bore nearly double the strain of Portland; but at forty-eight hours the Portland overtook it. At the end of seven days the Zumaya cement bore a strain of 518 lbs. He thought that the original test required by the Metropolitan Board of Works was 400 lbs. at the end of seven days,[1] and that this had been subsequently raised to 500 lbs.; his own test for Portland cement at the end of seven days was 750 lbs. If, as was probable, another cargo of the Spanish cement should be imported, he would test it further and lay before the Institution an account of the results he obtained. The superiority of this cement,

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It may be observed that Laurence Nowell, 1576, Dean of Lichfield's Map, has "y^e^ Gulf" written against the main, West of Mount's Bay; and Saxton's 'Anglia' Cornwall, Lord Burleigh's Book, Royal MSS., 18 D. III. B. Musm., 1579, has "The Gulfe" written against the Rock and not the Bay. Le Neptune François, quoted in y^e^ list, 1692, has "Golfe de Monsbaye" against the Bay (Mount's Bay). —J.B.R., April 25th, 1870.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 67.

in its quick-setting properties, over the Portland, was shown in the case of a temporary wall put up to protect works on a foreshore; the front of the wall was set in Zumaya cement and the back in Portland cement, when on the tide rising with a chopping sea which overtopped the wall, that portion of the back of the wall which had been set during the preceding tide was completely destroyed, while the front which had been set in the Zumaya cement remained entire. Mr. Coode added that the Zumaya cement did not weigh more than 84 lbs. to the bushel, and the cost in this country was only slightly in excess of Portland.

Mr. Beardmore remembered the late Mr. Walker mentioning the difficulties encountered in connection with the beacons on the Wolf Rock. It would be interesting to learn the cause of the destruction of the beacons, as associated with the unknown question of what was the maximum force of waves upon an object in the sea. From what he had observed of the action of the sea on the Edystone, he believed the ordinary circular form of lighthouses greatly mitigated the blows from the sea as compared with a breakwater.

Mr. M. Beazeley referred to the remark, that the present mode of construction of lighthouses was merely a reproduction of the Edystone: that was a mistake. The mode of dovetailing and joggling the stones together in the Wolf Rock lighthouse was entirely different from that adopted by Smeaton, and did not bear any relation to it. However excellent the mode in which the stones were put together at the Edystone, to prevent one stone from being drawn out without drawing out the neighbouring ones, it nevertheless formed no side bond from one stone to another. In the Edystone lighthouse there was no tie of stone from one course to another: but in the Wolf Rock lighthouse the stones had a side tie; they were dovetailed one into the other, and by means of the top band, the courses were so firmly tied together that one stone almost became part of the other stone; in fact, by this means there was such homogeneity of construction that, when the tower was put together, it became as it were one solid piece, and he could not conceive any other mode in which such uniformity of construction could be obtained. Then, again, this mode of construction did not interfere with the rapidity of setting the stones, which was of great importance, because, in a work like this, especially in the lower courses where green water was liable to come over the stones a short time after they were set, it was of vital consequence to get as great a weight put together in one tide as possible, and the stones when set formed such a tie, that when the water came over them they could not be displaced or lifted without the top band being torn away. That the dovetailing did not delay the setting of the work might be inferred from the fact, that it was a common

occurrence, when making two tides a-day, to discharge and set from twenty-eight to thirty-two stones from the barges, and those stones varied in weight from 2 tons to 3 tons each. The actual cost of the extra stone and the extra labour bestowed upon that apparently elaborate work, on the total cost of the stone dressing and of the stone, was under 5 per cent.; and the total cost of the dovetail bands, and extra stone on the whole cost of the work, was under 1 per cent. Considering that this mode of joining the stones insured the permanent stability and safety of the whole structure, 1 per cent. on the total cost of the tower was but a small addition. Nor must it be looked at in that light only, for if a course of stone had been lost from the effect of a heavy storm, it would have stopped the work for an entire working season. It was not only the actual small increased cost of this mode of preparing the stones which had to be considered, but the security obtained thereby whilst setting the courses, in such an exposed situation as the Wolf Rock. The term "Wolf," was quite modern, and had been applied to the rock almost within the recollection of persons living; in fact, many persons at the Land's End still called it, as it was spelt on old maps of the time of Queen Elizabeth and of Charles the Second, the "Gulf" Rock.

Mr. Parkes in explanation, said it was evident that the lower courses of stone exposed immediately to the wash of the sea should be set, whether dovetailed or not, in some quick-setting cement, and not in Portland. His remarks about Portland cement had reference to the courses above the immediate wash of the sea, where its strength might be considered as a substitute for dovetailing.

Mr. Douglass, in reply upon the discussion, said, that the surface of the Wolf Rock unfortunately dipped to the eastward, which was from the direction of the heaviest seas. At the outer part of the lower side of the rock, the masonry was let into the rock on an average about 12 inches, while on the opposite side the average depth cut was from 5 feet to 6 feet. In such a position it was decidedly the most economical and the safest course to excavate the whole surface of the foundation. In the case of the Long-ships, the rock was only cut away for the outer ring of masonry, and a core of the rock was left 12 feet high. The preparation of the foundation for a rock lighthouse was entirely dependent on the form and material of the rock. With some rocks it might be necessary to sink considerably deeper than with others. At the Wolf the rock was hard and compact, and the excavation of a few inches only on the lower side was necessary; but in the case of a softer rock, he should say it would be desirable to go much farther; for with a granite tower, which was supposed to last an indefinite time, provision should be made against the possible undermining of

the first courses of the masonry, by the natural decay of the surface of the rock at the base of the tower. The small additional cost of dovetailing work of this kind, viz., 1 per cent. on the total cost of the structure, or 5 per cent. upon the cost of the granite dressed, was scarcely worth considering. In preparing the design for a tower of this kind, the engineer had to adapt the height of the structure to local circumstances, and to provide cubical space for the efficient service of the light and for the comfort of the keepers. Then the material in the structure should be reduced to a minimum, because every unnecessary foot of material in the building was only adding so much unnecessary resistance to heavy waves; and on that account he considered every stone should be put together in the best manner, so as to produce, as nearly as possible, a solid post of granite. He believed this tower was so put together, that if held out horizontally it would not part from the rock. Again, dovetailing added considerably to the rapidity with which the work could be executed; and with the sea washing over the lower portion of the work, more stones might be set, dovetailed in this manner, than with any other system of dovetailing that he was acquainted with. If the stones were bedded in the ordinary way, the sea would force the cement out of the bed and joints; but with this method of dovetailing, the wash of the sea was only felt in front of the stone, and did not affect the bed or the back of the wall. He could never have risked cement rubble at the Wolf Rock. In some situations, no doubt, it might be used with advantage, but not in such an exposed position. The second beacon erected on the Wolf Rock was a cone formed of cast-iron plating, and filled with cement rubble. As each horizontal tier of plates was completed the cement rubble was built in, and left with its surface about 2 feet below the top of the plating. It often happened when the men returned to their work after stormy weather, that a great part of the filling was washed out, and many of the stones converted into boulders, by being churned in the iron tub or casing. If the rubble work had been fully exposed to the sea, it could be easily imagined that the whole would have been carried off.

The fog bell that had been put up, appeared, with the present knowledge of fog signals, to be the only one that could be used in this tower with advantage. The Daboll fog signals in use at St. Catherine's, Isle of Wight, and at Dungeness were worked by Ericson's caloric engines, of from 2 H.P. to $2\frac{1}{2}$ H.P., and the instruments were very efficient. That at Dungeness had been heard on board the Varne light vessel, at a distance of $11\frac{1}{2}$ nautical miles. A steam trumpet, designed by Professor Holmes, the inventor of the magneto-electric machine, in 1858, was exhibited at the Paris Exhibition, as well as the fog horn of Mr. Daboll, by the Corporation of the Trinity House. There could be no better proof of the

power of Professor Holmes' instrument than the fact, that it was forbidden to be blown in the park after the first day.

A comparison of the cost of the Wolf Rock lighthouse with other works of the same kind in Scotland and in England was attended with some difficulty. In the first place, there was the question of the height of the base above low water of spring tides; then there was the amount of the rise and fall of the tide, the exposure of the site, the distance from land, and other considerations; but he gave the particulars as follows:—

——	Total Cost.			Cubic Feet.	Cost per Cubic Foot.		
	£	*s.*	*d.*		£	*s.*	*d.*
Edystone . . .	40,000	0	0	13,343	2	19	11½
Bell Rock . . .	55,619	12	1	28,530	1	19	0
Skerryvore . . .	72,200	11	6	58,580	1	4	7¾
Bishop Rock. . .	34,559	18	9	35,209	0	19	7½
Smalls	50,124	11	8	46,386	1	1	7¼
Hanois	25,296	0	0	24,542	1	0	7¼
Wolf Rock . . .	62,726	0	0	59,070	1	1	3

Considering the exposed position of the Wolf Rock, the cost of the lighthouse erected there compared very fairly with the cost of any existing work of the kind.

Mr. Hawksley, Vice-President, said, he had been charged by the President to express his admiration for the Paper and for the drawings by which it had been illustrated; and to add, as must indeed be evident to every one, that the completeness of the communication in all respects could only have been arrived at by an expenditure of considerable time, trouble, and money, for which the thanks of the Institution were eminently due to Mr. Douglass.

March 8, 1870.

THOMAS HAWKSLEY, Vice-President,
in the Chair.

No. 1,245.—"Description of the Line and Works of the São Paulo Railway in the Empire of Brazil." By DANIEL MAKINSON FOX, M. Inst. C.E.[1]

THE São Paulo railway is the last in date of concession and of construction of the three Anglo-Brazilian railways, but if considered from an engineering or a commercial point of view, whether as regards the past difficulties and the cost of construction, the present success, or the prosperous future of the enterprise, it is entitled to the first place. Although the last to be realised, it is probable that the first railway project in the Empire was a line from Santos, passing by the city of São Paulo, into the interior of the province; for as early as 1837-8 such an idea was broached by Mr. Fred. Forum, an English merchant resident at Santos, and studies of a cursory nature were made under his auspices by Mr. A. de Mornay, and submitted to the late Mr. Robert Stephenson (Past-President Inst. C.E.), who reported thereon in 1839. It may be interesting to quote the following remarks by Mr. Stephenson, in recommending an easy valley line, in preference to a shorter line with heavy works: "What is of the greatest importance, it is entirely free from works of magnitude, such as render an accurate calculation of expense not only extremely difficult, but absolutely impracticable, for throughout my experience I have found that the application of ordinary estimates to works of extraordinary magnitude is worse than useless, as it never fails to mislead. This remark is peculiarly applicable to your project, for you are preparing to execute work in a country where the facilities are not only few but limited, where the simplest and cheapest, rather than the most refined and expeditious, methods of operation must be made available." The year 1839 was, however, too early an era for such an enterprise, and the project remained in abeyance until 1853-4, when it was revived under the auspices of the Baron de Mauá and other distinguished Brazilians. Preliminary plans were commenced, but not completed, owing to the stagnation of affairs

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

caused by the Crimean war. In the beginning of 1856, the scheme was placed by the Baron de Mauá in the hands of Mr. James Brunlees, M. Inst. C.E., who was charged with the preparation of the plans and sections, and of the report and estimates necessary for the organisation of a company in England, under the terms of the concession which was granted to the Baron de Mauá, the Marquis de Mont Alegre, and Councillor J. A. P. Bueno, by Imperial Decree of the 20th of April, 1856.

The concession is for a line of railway commencing at Santos, passing close by the city of São Paulo, and terminating at the town of Jundiahy, a distance of about 88 miles, with a guarantee of 7 per cent. interest on a maximum capital of £2,000,000 for a period of ninety years, with a right of preference for continuing the line to Rio Claro, a further distance of about 80 miles. These terms do not differ materially from those granted to the Pernambuco and the Bahia railways.

Early in 1856, the Author was sent out by Mr. Brunlees to undertake the preliminary surveys, and to furnish data for the plans, report, and estimates, which after having been presented to, and being approved by, the Imperial Government, should enable a Company to be formed, and contracts for the work to be entered into in England. The concession distinctly specified the termini, and to a certain extent the intermediate route of the line. The capital was arbitrarily fixed at £2,000,000, although the undertaking involved the construction of a first-class railway up the precipitous sides of the escarpment called the "Serra do Mar," which runs parallel to the sea coast, in a direction at right angles to that of the railway, and which rises abruptly to a minimum height of 2,500 feet above the sea level. No plans or sections, nor indeed any studies whatever, appear to have been previously made to determine the best mode and the probable cost of surmounting the barrier. This, it is obvious, materially affected the engineering of the line, as it was distinctly understood that no guarantee of additional capital would be allowed. The Author's instructions from England were to lay out a locomotive line over the Serra; but the first sight of the country convinced him that this could not be done and the line carried to Jundiahy within the prescribed capital. In consequence of his representations, Mr. Brunlees determined that inclined planes, with a gradient of 1 in 10 to be worked by stationary engines, should be employed, in order to shorten the ascent and enable the line to be made within the prescribed sum, and these inclined planes are the distinctive features of the railway. At that time surveys were being made for the extension of the Dom Pedro Segundo railway up the "Serra do Mar," near Rio de Janeiro. As the range at that point is about 1,000 feet lower than in the province of São Paulo, and the nature of the ground enables

the summit level to be reduced by tunnelling, a locomotive line with gradients of 1 in 55 has been constructed. Had a similar line been laid out on the São Paulo Serra, a continuous incline of at least 26 miles in length would have been entailed, and taking the cost of the Dom Pedro Segundo mountain line as a basis, the outlay for overcoming the Serra alone would have reached £1,500,000.

Only those engineers who have made surveys through tropical forests can form a definite idea of the immense labour involved in the exploration and selection of a railway route in a country like Brazil, and especially on the precipitous and rugged sea face of the Serra do Mar. To add to the difficulties, the whole escarpment, from the deepest gorge to the loftiest peak, is covered with almost impenetrable primeval forests, through which the explorer has to drive narrow paths resembling 'headings.' The exploring party usually remained in the jungle three weeks at a time, living in huts covered with the leaves of the palmetto, exposed to tropical rains and hardships of which it is difficult to convey an adequate idea, and emerging from the woods blanched from want of sunlight, which rarely penetrates the thick gloom of a Brazilian forest. From the neighbourhood of São Paulo to Jundiahy, the plans and sections drawn in 1835 were verified and made use of, where practicable. The whole of these surveys were completed in about fifteen months, and the Author returned to England in September, 1857. At the close of that year Mr. Brunlees, the Engineer-in-Chief, presented his plans, sections, report, and estimates, which by Decree of the 11th March, 1858, were approved by the Imperial Government of Brazil, with such slight modifications, to insure uniformity with other Brazilian railways, as were proposed by the Government consulting Engineer, Mr. C. B. Lane, M. Inst. C.E.; and by Decree, dated the 13th of March, 1858, the period for the formation of the Company was prolonged for two years, or until the 26th of April, 1860, and the concession was altered in details relating to the guarantee. By Imperial Decree of the 30th of October, 1859, the guarantee was extended to the whole period of the concession, ninety years, and provision was made for interest paid during construction being treated as capital, to bear the guaranteed rate of interest. The Company was formally incorporated under memorandum and articles of association bearing date the 22nd of December, 1859, and in January, 1860, the Author, having been appointed by Mr. Brunlees as his principal resident Engineer, proceeded to São Paulo to take charge of the works, and was shortly followed by Mr. Aubertin, the Company's superintendent, Mr. Bolland, M. Inst. C.E., Mr. John Henderson, Assoc. Inst. C.E. (the contractors' Engineer), and others. On the 8th of February, a contract between the Company and Messrs. Robert Sharpe and Sons was entered into, whereby the

contractors undertook to acquire the land, execute the works and buildings, and supply all rolling stock and plant, in conformity with Mr. Brunlees's plans, sections, and specifications, for a total sum of £1,745,000. A period of eight years, or to the close of 1867, was allowed by the contract for the completion of the works. The first sod was turned in May, 1860, the rails were laid to Jundiahy early in July, 1866, the line was conditionally accepted, subject to completion during maintenance, in October, 1866, and was finally opened for traffic, with the provisional consent of the Government, on the 16th of February, 1867, thus saving ten months of the contract time. By virtue of a contract between Messrs. Sharpe and the Imperial Government, the contractors received a bonus of £43,750 for the saving of time thus effected, which was repaid to the Government by an addition to the tariffs of about 5 per cent. In addition to the contract sum, the contractors, in virtue of subsequent arrangements, and on account of extra cost of stations, &c., were entitled to receive £72,917, making the total paid to the contractors £1,817,917, exclusive of the Government bonus.

When the line was accepted much remained to be done, which the contractors undertook to execute during their term of maintenance, and when the line was provisionally accepted by the Government, an agreement of a stringent nature was entered into by the Company with the Government, which, owing partly to unprecedented rains and floods in the end of 1867 and the beginning of 1868, was not fulfilled until July, 1868, when the line was finally accepted.

The line has been worked ever since the opening with most satisfactory results, both as regards receipts and working expenses; and had the rate of exchange been at par, the traffic during the half-year ending June 30th, 1869, would have been sufficient to pay the full dividend of 7 per cent. on £2,650,000 without the assistance of the Brazilian Government.

Before proceeding to the special object of the Paper, it is thought that a brief description of the physical characteristics, productions, climate, &c., of the province will be of advantage.

The Province of São Paulo lies immediately south of Rio de Janeiro, between 20° and 26° south latitude. It comprises an area of about 95,000 square miles, thus ranking ninth amongst the Brazilian provinces in extent of territory. The population, about 900,000, is only inferior to that of Rio de Janeiro, Minas Geraes, Bahia, and Pernambuco, whilst in material advantages, affecting the powers and variety of production, and in salubrity of climate, San Paulo is entitled to perhaps the first rank. Situated on the verge of, and not within the tropics, the climate is modified by the elevation of the province. An area of about 90,000 square

miles out of the 95,000 square miles is an elevated plateau, inclining, however, as the flow of the rivers indicate, gently inland towards the Parana, from the crest or summit of the "Serra do Mar." This mountain range, as already stated, rises abruptly to a height of from 2,500 feet to 3,000 feet above the level of the sea, forming a sea cliff, the summit of which, in this province, is rarely more than from 10 miles to 15 miles from the shore line, which at no very remote geological period has been coincident with the base of the mountain itself. The sea face of the Serra is broken up into the wildest gorges and ravines by numerous mountain torrents, but no river or stream of any magnitude finds its way down the Serra, nor is there any gorge or pass of importance to break the uniformity of level of the summit. The narrow belt of country intervening between the sea coast and the foot of the Serra, is an alluvial deposit, in places forming an almost impassable salt marsh, covered with mangrove trees, and intersected with occasional spurs from the Cordilléra, which terminate in bold bluffs; or relieved by insular oases of high and dry ground, which rise prominently from the surrounding marsh. On such an island is built Santos, the seaport of the province, and the eastern terminus of the railway, on the shores of a bay which forms a well-sheltered harbour, readily entered by large vessels at all states of the tide. Although the seaboard of the province is 300 miles in extent, there is no other seaport worthy of the name along the coast. It will thus be seen that Santos, at present a small but thriving city of about 10,000 inhabitants, must eventually be a place of great commercial importance, as the only outlet and inlet to the entire province, which lies almost wholly on the high land above the mountain barrier.

São Paulo, the capital of the province, the seat of a university, and the largest inland town of the empire, is situated on the line of railway, about 48 miles from Santos. But the fertile district peculiarly adapted to the cultivation of coffee, the staple of the province, commences about 100 miles from the sea coast, in the neighbourhood of the city of Campinas, and about 30 miles beyond the terminus of the present line at Jundiahy. The cultivation of the coffee-plant is comparatively recent in this province, having only been introduced in 1840. There are, however, already in the province about thirty million trees, producing an average annual yield of 80,000,000 lbs. of coffee, and fresh plantations are year by year being added to those now existing. But, although coffee is the staple of this rich district, other tropical products, such as cotton, sugar, tobacco, rice, Indian corn, beans, arrowroot, tapioca, indigo, as well as the cereals and fruits of Central Europe, are cultivated in the interior. Cotton, especially, bids fair to rival in importance the cultivation of coffee, such has been the stimulus

given to its culture by the high prices caused by the civil war in the United States.

The principal engineering features of the São Paulo railway (Plate 5) will now be noticed:—first, of the locomotive line both below and above the Serra,—and then of the inclined planes by which the ascent of the "Serra do Mar" is accomplished, with the mode of working them.

Santos to foot of Serra (13½ miles); Lower Locomotive Line.

This portion of the railway runs over the low swampy ground which intervenes between the seaboard and the foot of the "Serra do Mar," and for the first 8 miles consists of a low embankment, alongside the existing public road constructed by Government over the marsh. Leaving the road, the line crosses the valleys of the Cubatão and the Mugi rivers, both subject to high and dangerous floods from the mountains, by embankments of considerable magnitude, and terminates at the foot of the spur of the Serra which has been selected for the inclined planes. There are three principal bridges on this length. The first, across the arm of the sea which divides the island on which Santos is situated from the mainland, is 500 feet in length, consisting of ten openings of 50 feet, each spanned by wrought-iron lattice girders placed under the rails, supported on piers composed of single rows of four cast-iron screw piles, 15 inches in external diameter. The bridge over the Cubatão river has four spans of 75 feet each, with lattice girders supporting cross-plate girders, the piers consisting of cast-iron cylinders 18 inches in diameter, also on screw foundations; and the bridge over the Mugi river is of three spans of 66 feet, also composed of lattice girders resting on cast-iron columns. There are six other bridges, with spans varying from 15 feet to 40 feet, all of wrought iron, resting on cast-iron piles, or on stone abutments. The steepest gradient is 1 in 75, for 51 chains, and the sharpest curve is 17-chains' radius. At the terminal station at Santos, a wharf was constructed on cast-iron piles, with creosoted pine superstructure, and a junction line affords direct communication with the harbour. The buildings for the passenger station and general stores are of masonry, but the goods sheds, engine and coke sheds, &c., are of corrugated iron. The intermediate stations are of brickwork. Great difficulty was experienced on this section in obtaining suitable ballast, as the sand available was much too fine, and broken stone is inapplicable for 'pot' sleepers.

Summit of Serra to Jundiahy (68 miles); Upper Locomotive Line.

The locomotive line recommences at the summit of the Serra, and runs in a N.W. direction, for a distance of 30 miles, to the city of São Paulo. In the neighbourhood of the Serra the earth-

works are of considerable magnitude, most of the excavations being through schistose rock. The line is undulating for the first 12 miles, crossing a succession of short ridges and valleys, with occasional deep cuttings and embankments, after which it follows the course of a valley to São Paulo, with easy gradients and works. The steepest gradient on this section is 1 in 50. The station at the Alto da Serra is unavoidably placed on a curve of 12-chains' radius, but apart from this the sharpest curve is 20-chains' radius. There are two iron bridges, each consisting of lattice girders of 40 feet span, supported on cast-iron screw-piles, and four minor bridges from 15 feet to 40 feet span, erected on a similar principle. There are also one hundred and twelve bridges and culverts of substantial masonry, having openings of from 2 feet to 18 feet.

The central station at São Paulo is situated on a level stretch at the summit of inclines of 1 in 60; and ample accommodation for the passenger and goods traffic is provided, with carriage sheds, and workshops for the repairs of the locomotives and rolling stock generally. The head offices of the administration of the Company are situated at São Paulo. There are also two small roadside stations, both provided with sidings, and one with a goods shed, and a small suburban station near São Paulo. All the stations are substantial and neat buildings of brickwork with tile roofs.

From São Paulo to Jundiahy, the present terminus of the line, the distance is 38 miles. Its engineering character is similar to that of the district between the top of the Serra and São Paulo, though the country is more difficult, and the works heavier. After crossing the river Tiété, the main drain of the district, about 7 miles from São Paulo, there is no leading valley to follow, and the railway is, for the most part, carried across a succession of valleys and ridges. The steepest gradient on this section is 1 in 40, for a distance of 1½ mile, and the sharpest curve is 17-chains' radius. The bridge over the Tiété consists of six openings of 33 feet 4 inches, spanned by lattice girders, supporting cross-plate girders, on which are placed longitudinal balks for carrying the rails. The piers are cast-iron cylinders 2 feet in diameter, sunk to the rock, with a centre pier of masonry on an isolated rock. Another bridge, of three spans of 30 feet, and two single-span bridges of 30 feet and 40 feet, are of a similar construction. There are also one hundred and forty-three culverts, mostly of masonry, and, where practicable, open, with iron or timber girders, and three under road bridges of substantial rubble masonry.

A tunnel, 650 yards in length, was unavoidable at the summit of the gradient of 1 in 40, and a cutting at the northern approach, 30 chains' in length, which was a source of great trouble. The tunnel for a length of 370 yards is driven through mica schist of a hard and coarse description, with large quantities of quartz, and

veins of trap intersecting the rock. Sometimes it was not possible, with four hammers, to advance the bottom heading, 14 feet by 9 feet, through the rock, more than from 12 inches to 18 inches per day of twenty-four hours. The rest of the tunnel, 280 yards in length, was through earth. The side walls and haunches are of rubble masonry, with the crown of the arch, for 10 feet, of brickwork. Two shafts, one of which was 190 feet in depth, were sunk to expedite the work.

In the summit cutting north of the tunnel, a slip or landslide on a large scale threatened to endanger the stability of the line. It was temporarily overcome by driving heavy piles along the face of the slip, with transverse stretchers, placed about 3 feet under the rails, on which broken stone was laid. The movement continued, however, and in the commencement of 1869 a solid invert of stone, 12 feet deep, and for the whole width of the formation, was placed under the road bed in 8-feet lengths, without interfering with the traffic. The piles were then cut down, and a retaining wall was built.

The earthworks on this division have amounted to about 40,000 cubic yards per mile; but the quantities were increased by the contractors preferring to run their cuttings to spoil, and to make up the banks from side cuttings. The maximum depth of cutting is 74 feet, and the maximum height of embankment is 70 feet. The average slope of the cuttings is from $\frac{3}{4}$ to 1, to 1 to 1, and of the embankments $1\frac{1}{2}$ to 1.

The terminal station at Jundiahy is of a most inexpensive description, as it would have been unwise to spend money unnecessarily on a station, which must, as the line is extended, become of secondary importance; but ample goods sheds and yard room have been provided, with an engine shed for four engines, coal platform, tank, carriage shed, &c.

There are three small roadside stations, two of which are provided with sidings, but no goods sheds.

Serra Inclines.

The laying out of the works of these inclines was a task of no ordinary difficulty, as in addition to the precipitous and inaccessible nature of the ground, the whole mountain side was covered by impenetrable forest. Nor was the difficulty confined to the engineers who were the pioneers in this desolate region; the contractors who followed them had to make roads, and undertake preliminary operations on a scale and to an extent never contemplated by those who have only carried out railway works under ordinary circumstances. Those about to undertake the responsibility of executing works in an unexplored and sparsely inhabited

region, cannot be too careful in ascertaining how far allowance has been made for contingencies of the nature referred to.

The length of the inclines is about 5 miles, the rise being 2,557 feet above the foot of the Serra, or 2,652 feet above the sea level. There are four inclines, each with a gradient of 1 in 9·75, and 6388, 5842, 6876, and 7017 feet long respectively. At the top of each incline there is a bank head, about 250 feet in length, with an inclination of 1 in 75 downwards, where the stationary engines are placed. The radii of the curves range from 30 chains to 80 chains. The earthworks on these inclines are of extraordinary magnitude. Not only are the cuttings and the embankments of great depth on the centre line of the railway, in some instances as much as 75 feet and 95 feet; but owing to the steep cross section and the treacherous nature of the ground, the slopes of the cuttings on the upper side, although never flatter than $1\frac{1}{4}$ to $1\frac{1}{2}$ to 1, are in some instances 330 feet in length, whilst the inferior slopes of the embankments are of corresponding extent. Nearly all the banks are secured by heavy dry stone retaining walls, varying in height from 10 feet to 60 feet. Earthworks of this nature were subject to extensive and sudden slips from the mountain side, and embankment after embankment was carried away during construction, often after completion to the formation level. The only effectual mode of stopping these slips, which threatened permanently to endanger the stability of the line, was by a thorough system of drainage, searching for, and gathering all the water on the upper side of the railway, and conducting it across the line as often as possible in pitched channels set in cement; by pitching the entire surface of the inferior slopes of all the embankments, thus preventing wash; and by draining the upper slopes of the cuttings, and securing the same by massive retaining walls. These measures have been so far successful, that during the two last wet seasons not a single slip either in cutting or bank occurred on the Serra works. An extensive slip from the mountain in one of the largest cuttings, during the term of maintenance, was cleared out by the agency of water. A considerable mountain stream was diverted into the cutting, and as many men as could be crowded on, pulled down the soil, others working it up; the force of the water on the incline of 1 in 10 rapidly carried the soil away, leaving behind the stone which was available for pitching the banks, &c. It is estimated that 1,200,000 cubic yards of excavation in cuttings and borrow pits were taken out. No attempt at equation of cuttings and banks was made, as owing to the precipitous character of the ground, haulage for even ordinary distances was impossible. Less rock was met with than was to be expected, the proportion between rock and earth being probably 1 to 10; but abundance of good building stone was always close at hand. There are fifty-

eight culverts, varying from 3 feet to 10 feet opening, which in every instance have been proved fully equal to the discharge of the torrents during the greatest floods.

At the foot of the fourth incline a chasm of more than ordinary depth has been crossed by an iron viaduct (Plate 6). It is 705 feet in length, and consists of ten spans of 66 feet, and one of 45 feet. The greatest depth from the rails to the ground is 185 feet. The abutments are of substantial rubble masonry, with hammer-dressed string course and coping. The piers are ten in number, and of varying heights according to the section of the gorge. Each pier is composed of eight cast-iron columns, four of which carrying the main centre girders are vertical, the four outside columns raking transversely with a slope of 1 in 12. The columns, 12 inches in external diameter, are firmly braced together horizontally, at perpendicular distances of 10 feet, by double T-irons, and diagonally by wrought-iron tie bars. The columns rest on cast-iron foundation pieces, firmly united by cast-iron tie girders, and bolted down to a base of solid ashlar masonry. The superstructure consists of four wrought-iron lattice girders, two of which are placed under the rails. The girders are braced together in the usual way, and rest on cast-iron bed plates, designed to brace firmly together the columns in the piers, and at the same time to provide for the inclination of 1 in 9·75, and to act as sliding plates on which the girders can move within certain limits. The rails are fixed on native timber cross-sleepers, 12 inches square, and planks 2 inches thick are laid between the sleepers. No scaffolding was used during the erection. An iron wire rope was stretched across the chasm, and piece by piece of the columns was lowered into its place, by means of a block and pulley running along the rope, with the necessary tackle. The piers were thus run up simultaneously, or, at least, independently one of the other. The danger of their being blown down, when they reached a certain height, by the furious winds to which the locality is subject, was guarded against by simply laying a balk, 66 feet long, from pier to pier about the mid height of the structure, which, with a temporary hand-rail, served as a bridge for the men engaged on the work. The girders were erected by means of a crane, with a jib reaching half the span, mounted on a suitable frame and wheels. On the completion of the first pier, the girders were one by one placed 'in situ' from the abutments. The road was then made good over the first span, and the crane moved to the first pier, when the girders were deposited for the second span, over which the road was then laid; and this process was continued until the viaduct was completed. The first stone was laid on the 22nd of July, 1863; but, owing to difficulties inseparable from such a work in such a situation, principally to the impossibility of getting the material on

the ground until the inclines below were completed, the ironwork was not fairly commenced until March, 1865, and the first train passed over the viaduct on the 2nd of November in the same year. This structure is built on a curve of 30-chains' radius, and on an incline, as before stated, of 1 in 9·75. The weight of wrought iron in the girders and piers is 562 tons, and of cast iron in the columns 480 tons. The abutments and piers contain 5,700 cubic yards of masonry.

The buildings for the engines and the boiler houses are of substantial rubble masonry, the engines being bedded on ashlar foundations.

The permanent way is laid upon transverse sleepers of native timber, to which also the pulleys are attached. The rails weigh 65 lbs. per yard, but are of a special section giving a greater depth than usual, in order to afford a sufficient grip for the safety 'clip' break.

Mode of Working the Inclines.

The inclines are worked by what is known in the north of England as the 'tail end system,' and are thus partially self-acting, wagons being attached to each end of the rope, and being raised and lowered simultaneously. The arrangement of the rails is peculiar (Plate 7). On the lower half of each lift an ordinary single line is laid, and on the upper half (above the passing place) three rails are laid, forming a double road with a centre rail common to both. Exactly half way on each lift, the single line of the lower half and the three rails of the upper half branch out into a double line of way, of sufficient length for the up and down trains to pass, with a 6-feet space between the tracks. The switches at the lower end are self-acting. This arrangement enables two lines of pulleys for carrying the ascending and descending part of the rope to be laid down above the passing place, whilst on the lower half a single line of pulleys only is required. At the bank heads three separate lines of way about 250 feet in length are provided, the up traffic being alternately run on to one or the other of the side lines, the down traffic being always worked on the centre road. These lines are laid to a down gradient of 1 in 75, which is sufficiently steep to allow the wagons to trail the rope out from the engine. The ropes are 4 inches in circumference, and are of steel wire, No. 10 Birmingham wire gauge. There are six strands, with seven wires in a strand. They are tested to 35-tons' breaking strain, the maximum working load, as shown by the dynamometer, being from 4 tons to 4½ tons. Their duration is about two years. The ropes run in light pulleys of wrought iron, with a cast-iron core 12 inches in diameter, placed from 5 yards to 7 yards apart on the curves, and 10 yards

apart on the straight lines. Extra strong and carefully made sockets are fixed to each end of the rope, with swivels to allow for undue twist in the rope to be worked out. The ropes pass to the engines round horizontal pulleys 10 feet in diameter.

The winding machinery at each bank head consists of a pair of non-condensing horizontal engines of 150 nominal H.P. The cylinders are 26 inches in diameter, with a stroke of 5 feet, and are run at a speed of 22 revolutions per minute, with 30 lbs. pressure of steam in the cylinders. Simplicity and durability were studied in the design of the engines; the workmanship is first-class; and, although they have been at work for five years, no repairs of any importance have been required.

Motion is given to the rope by means of friction gearing, consisting of two pulleys of 10 feet in diameter, the upper one fixed on to the fly-wheel shaft having three grooves, and the lower one, running loose, with two grooves, round which the rope is passed in the form of the figure 8. The engines are fitted with a powerful break round the fly-wheel, and with an indicator, which shows the driver the position of the train on the incline. Each pair of engines have five Cornish boilers 26 feet long, and 5 feet in diameter, with 3-feet internal flues. Three boilers are ordinarily sufficient to supply the engines with steam. The best Newcastle coal is used, and the consumption per hour, per square foot of fire grate, is about 9½ lbs.

Special break wagons go up and down with every train. The draw bars are made movable, so that by raising and lowering them according to the weight of the train, the rope can be made to enter the pulleys on the curves with certainty. In addition to the ordinary break block acting on each wheel, and worked in the usual manner, there is a specially-designed safety break (Plate 7), which clips the rails, and by means of which, in case of emergency, a train can be brought to a standstill in the length of a few yards. The pair of levers which form the 'clip,' are worked by means of a right and left screw turned by a wheel, four revolutions of which screw the break, so as firmly to grip the rails. The 'clip' when not in use is suspended over the rails by a balance weight, being kept in place by guide blocks working in iron plates, and being lowered in a moment for action by pressing a lever with the foot. In addition to their value as a safety break, the 'clips' have often to be used in misty weather, when the rails are greasy on the bank heads, in order to pull up the train at the right place.

Telegraph signals are used in working the inclines. In addition to this, each lift is provided with a draw wire signal, by means of which the guards in charge of the train can communicate with the engine house, and stop the train at any part of the road.

The load at present is limited to three carriages or wagons,

besides the special break van to which the rope is attached. The weight of three loaded wagons is about 34 tons, and the break van 6 tons, making a total weight of 40 tons as the maximum load, of which 21 tons is paying load. The time occupied on each incline is about fifteen minutes, or one hour for the whole ascent of 2,550 feet. As four trips can thus be made in the hour, twenty-four wagons containing 168 tons can be raised and lowered per hour, or two hundred and forty wagons with 1,680 tons of paying load per day of ten hours. The whole ascent could easily and safely be made in three-quarters of an hour, thus increasing the capacity of the inclines 33 per cent. Since the opening of the line, on the 6th February, 1867, the inclines have been worked without accident to either passenger or goods train.

The engines and boilers were built by Messrs. Fairbairn and Co., of Manchester, and the ropes were originally supplied by Messrs. Wright and Co. The mechanical arrangements of the inclines were designed, under Mr. Brunlees's direction, by Mr. R. F. Welby, who also superintended the erection of the machinery in Brazil.

The permanent way throughout consists of a rail of the double T form, weighing 65 lbs. per lineal yard. The rail is not, however, reversible, the upper flange being $2\frac{1}{2}$ inches wide on the tread, and the lower flange 2 inches wide on the base. On the Serra inclines, the depth of the rail was increased from 5 inches to $5\frac{1}{2}$ inches in order to afford a hold for the 'clip' break, but without adding to the sectional area. On the locomotive line the rails are laid on Greaves' cast-iron sleeper-chairs, 3 feet apart, with wrought-iron tie-bars connecting each alternate sleeper. The rails are fixed by compressed wood keys, placed inside, and are fished throughout, the joint being placed over a chair on which is cast a fishing piece for the outside of the rail, a wrought-iron fish being placed on the inside, and the whole secured by four $\frac{7}{8}$-inch bolts. On the Serra, and for a length of 2 miles in the neighbourhood of the tunnel, transverse sleepers of native timber have been used, the rail being fixed on ordinary cast-iron chairs, spiked to the sleepers in the usual manner.

The Author from experience can report favourably of the iron pot-sleeper system of permanent way, in such a country as Brazil. Not only are the sleepers easily transported and handled, but they are quickly and well laid by native labourers, and they make a good and durable permanent way, easily and cheaply maintained, and not too rigid for any velocity at which it would be prudent or economical to work railways laid out with gradients of 1 in 50 and curves of 20-chains' radius. The most suitable ballast is disintegrated granite or gneiss, and gravel or coarse sand; but even sandy clay, or earth mixed with sand, may be used. Care should be taken to secure thorough surface drainage, which, with iron

sleepers laid in non-porous ballast, is indispensable. Broken stone is unsuitable, on account of breakage. Though many of the embankments vary from 30 feet to 60 feet in height, and were during construction constantly subsiding under the heavy rains, no extra breakage of the pot-sleepers is attributable to this cause. Occasionally on high banks, which had subsided, additional bearing was given by introducing native cross-sleepers, of any timber that came to hand, under the rails, between the cast-iron chairs, which served the purpose until the bank became consolidated. The only breakage, to any extent, was caused by the manner in which the sleepers were knocked about, from the time they left the ship until they were placed in the ground, it being almost impossible in the hurry of construction, especially by contract, to insure the careful handling of materials. Although there exists in the Brazilian forests abundance of timber suitable for sleepers, if carefully selected, cut at the proper time, and seasoned before use, it is practically impossible to obtain a supply of suitable quality, in sufficient quantity for the rapid construction of a line. The Engineers and Contractors' Agents being ignorant of the qualities of tropical timber, had to seek for information, which rather confused than guided them, until they had facts of their own to depend upon. The consequence was that on the Serra, the sleepers, inspected and marked by an inspector named by the Government Engineer, had to be removed in some instances a few months after they had been laid. Creosoted pine has not been used for sleepers on this railway, except on the bridges on the first section, where it has lasted well; cross-ties and longitudinals on the Santos wharf and on the Casqueira Bridge being as sound now as when first laid five years ago. The Author is of opinion that it would be difficult to find a system of permanent way better adapted to inter-tropical countries, than the iron-sleeper chair road. He would, however, suggest the following modifications as the result of his experience on the São Paulo railway. Instead of having three kinds of 'pots,' one for the joint chair, another for the tie-bar, and a third intermediate, all the pots should be cast of one pattern, to admit of a tie-bar being used if required. No joint chairs should be used; the joint should be suspended between two pots, placed close together without contact, and fished with two wrought-iron plates in the usual manner. Great inconvenience was caused in laying the road, partly owing, no doubt, to want of careful management, by the multiplicity of parts; at one time joint pots were wanting, another day tie-bar or intermediate pots, and work had constantly to stand still, or be done imperfectly. In foreign countries, uniformity and simplicity of design are most important considerations. The Author also found the joint between two chairs placed as near as possible together, and fished, made a

better job than when placed immediately over the chair and sleeper.

The fencing found most suitable, above the Serra, was an iron wire fence with wrought-iron standards, placed on the inside of a ditch, from 5 feet to 7 feet deep. On the first section a quick-thorn hedge has been planted, and affords good protection.

The telegraph, which consists of two wires, is supported on wooden posts of native timber, requiring frequent renewal. The poles, 18 feet long and 6 inches thick, cost about 3*s.* each. On the first section channel-iron supports are used. Needle instruments are employed throughout.

The length of the line on curves is 36 miles 68 chains, of which 27 miles are under 30-chains' radius; the length of straight lines being 49 miles 46 chains. A classified abstract of the curves and gradients is given in Appendix A (page 50).

It will be seen from the preceding description, that the São Paulo railway has been constructed upon the model of good European railways, and the works are of a substantial and durable character, (which alone are suitable for the tropics,) and capable of serving for the traffic of the entire province, which must be transported up and down the "Serra do Mar."

The geological formation of the district is glacial drift, lying immediately on primary rocks, which, on the lower part of the Serra, are mainly granitic; farther up gneiss predominates; and at the top of the Serra and inland, mica, schist, clay, slate, and the various rocks usually found in metamorphic formations form the basis on which rests the superincumbent drift. These rocks, near the surface, are much decomposed or disintegrated, and often reduced to the condition of a soft paste, though possessing the appearance and elements of the primitive rock. Trap dykes and veins of quartz intersect the underlying rocks. The drift consists mainly of an ochreaceous, ferruginous, sandy clay, almost destitute of stratification, and full of a variety of boulders, of various dimensions and composition, and is generally divided from the solid rock by a thin layer of water-worn pebbles, varying from a few inches to a few feet in thickness. The boulders are often greenstone, composed of feldspar and hornblende, or of granite. In the wider valleys there is a considerable depth of alluvial silt, with occasional beds of dark blue, unctuous clay, and layers of peat-moss, and clay-marl. The geological character of the district generally is favourable for engineering operations, although on the Serra the facility of excavating was, perhaps, more than counterbalanced by the perishable nature of the material. Above the Serra the red sandy clay and decomposed rock are easily excavated,

and stand at favourable slopes, and the latter forms good ballast. There was a deficiency of building stone, except on the Serra, where good stone, easily quarried, was abundant. No limestone is found in the district, the lime used being either shell lime from Santos, or brought about 40 miles from the interior. The water from the drift is pure, and suited for locomotive use. The Author is indebted to Professor Agassiz for information on the geology of the district.

The climate of the plain near the sea level, and that of the highlands above the Serra, are distinct, both as regard temperature, moisture, and rainfall. The abrupt sea face of the Serra arrests the clouds borne by the south-easterly winds from the Atlantic, and is subject to floods of rain, which does not, however, extend far from the crest of the mountain. The wet season commences about the end of October, and continues until March; but, although the wet and dry seasons are distinctly marked, there is not the same regularity, either as regards the period or the rainfall, that is observed in the tropics generally.

The following Table shows the height above the sea of various stations along the railway, with the average temperature and rainfall, where observations have been kept, over a period of six years, ending December, 1868:—

Stations.	Average Daily Temperature in Shade.		Rainfall.	Height above High-water Mark.	Distance from Sea.
	Minimum.	Maximum.			
	Fahrenheit.	Fahrenheit.	Inches.	Feet.	Miles.
Santos	60°	92°	130	7	
Foot of Serra	..	..	..	68	
Top of Serra	38°	85°	176·5	2,625	12½
Rio Grande	..	..	..	2,455	
Tamandatahy Summit	..	..	..	2,637	
São Paulo	40°	90°	44·6	2,419	35
River Tiété	..	..	..	2,368	
Taipas Summit	..	..	..	2,669	
Juqueri Valley	..	..	..	2,360	
Tunnel Summit	..	..	..	2,736	
Jundiahy	40°	90°	42	2,320	65

The locomotives furnished under the contract by Messrs. Sharp, Stewart, and Company, are of first-class workmanship. Three are small tank engines, especially designed for the lower locomotive line. The tank engines for the upper line have 15-inch cylinders and a stroke of 20 inches, with low driving-wheels, coupled, 5 feet in diameter, and two leading wheels of 3 feet 6 inches in diameter. The tender engines have 16-inch cylinders and a stroke of 22 inches; the four driving-wheels, coupled, being in front, also 5 feet in diameter, and the trailing-wheels 3 feet 6 inches in diameter. Sub-

sequent to the opening of the line, six goods engines, more adapted to the requirements of the unexpectedly heavy traffic, were sent out. Two were furnished by Messrs. Sharp, Stewart, and Company, and four by the Avonside Engine Company. These engines have all 16-inch cylinders and a stroke of 24 inches. Those furnished by Messrs. Sharp, Stewart, and Company have six wheels, all coupled, 4 feet in diameter, with a wheel base of 14 feet 3 inches; the trailing-wheels being fitted with an axle-box admitting a lateral motion. Those furnished by the Avonside Company have eight wheels, six of which are 4 feet in diameter and coupled, and the leading wheels, 2 feet 9 inches in diameter, are fitted with Mr. Bridges Adams' radial axle-boxes. The total wheel base of these engines is 16 feet 9 inches, the distance apart of the centres of the extreme coupled wheels being 11 feet. Both the front and the trailing coupled wheels have a lateral movement (regulated by horizontal springs), the joints of the coupling-rods being fitted with a ball-and-socket joint, to allow the requisite play. They are fitted with sand-boxes worked from the foot-plate. Each of these six engines takes a gross load of eleven wagons, or 130 tons, at a speed of 8 miles per hour, up the incline of 1 in 40, with a pressure of steam in the boiler of 130 lbs. per square inch. The Author is of opinion, that, in consequence of the excessive heat and dryness of the rails, on all lines in the tropics, where the curvature is excessive not only in radius but in length, it will be found advantageous to use the bogie or radial axle, and to lessen the rigid wheel base as much as possible. The rapid destruction of the wheel-tires is a matter of serious consideration, and although steel tires are now exclusively employed, they soon require turning up. Steel tires taken from the leading driving-wheels of one of the original tender engines, with six wheels, four being coupled, and 5 feet in diameter, the engine weighing about 27 tons, ran 32,000 miles before they were turned up, and 19,000 miles since; they are now useless after running 51,000 miles. The rigid wheel base of this engine is 13 feet 8 inches. Low Moor tires previously used on the same engine ran about 30,000 miles. (Appendix E, page 52.)

The carriages and original goods wagons were constructed by the Ashbury Company, of Manchester. The passenger carriages have oak frames and varnished teak bodies, and they have given satisfaction; but the woodwork in the goods stock has deteriorated rapidly, and renewals are being constantly effected with native timber. Great trouble was caused by the roofs and sides leaking. The best roof is one of zinc, care being taken to allow for the excessive contraction and expansion of that metal. Twenty covered wagons have sides of sheet iron screwed to timber framework, with corrugated iron roofs, and are the best on the road, though somewhat heavy. The Author is convinced that wagons for hot climates

should have a lower framework of iron, the sides being of the lightest obtainable wood that is, at the same time, sufficiently durable, and a roof of zinc properly laid to allow for expansion at the joints.

The only railway materials obtainable in the province are timber, stone, bricks, lime, and ballast. Although there is an abundance of good timber in the forests suitable for railway work, at the commencement of extensive works in Brazil, it is advisable to be provided, especially for works on the seaboard, with pitch pine, which can be had of any length, or scantling, and is much more easily wrought than the hard Brazilian timber. In the interior, however, native timber can be obtained at a moderate price. Scantling 8 inches square, and 20 feet to 35 feet long, costs about 1*s.* 6*d.* per cubic foot; and balks roughly hewn, 1 foot square, can be delivered on the railway for less than 1*s.* 6*d.* per cubic foot. Where wooden sleepers were used they are being renewed as required with selected native timber cut at the proper time of the year, and stacked for use. Sleepers 9 feet long, by 10 inches wide and 5 inches thick, cost from 1*s.* 6*d.* to 2*s.* each, and last from three years to five years.

Inland there is a scarcity of suitable building stone. All old buildings in São Paulo are built of pisé or rammed earth, locally called 'taipa.' This mode of construction has, however, been latterly superseded by brickwork; good bricks are made, there being two or three of Clayton's machines at work in the province. The bricks used in the tunnel were made on the spot by the contractors. The great defect of native-made bricks is, that they are rarely sufficiently burnt. Native brickwork is invariably roughly done, without regard to bond, line, or level, and is finally covered over with plaster. Some of the station buildings are fair specimens of brickwork, built, however, by English, German, and Portuguese masons. The price of bricks, 11 inches long by 5½ inches wide, and 2½ inches deep, has varied from £2. 10*s.* to £5. 10*s.* per thousand, the present price for good bricks being about £3.

Only one bed of gravel, of sufficient thickness to pay for working, was found along the whole railway. The line has been almost entirely reballasted, since the opening, with this gravel, or with a decomposed granite forming a ballast thoroughly adapted to the pot sleepers.

The scarcity of stone led to the general use of iron screw-piles as foundations for the girders, in place of stone piers or abutments; the ends of the embankments being pitched with stone after the rails were laid. For like reasons iron goods-engine and coke sheds have been supplied from England, although more expensive than buildings of native materials. The Author's experience is wholly against the use of corrugated iron as a roofing material for railway buildings, on the ground of expense, destructi-

bility, great heat, and the difficulty of making it water-tight. Nothing is so good, where ventilation is an important consideration, as the ordinary Portuguese tile of the country, and for small spans it is cheaper than corrugated iron, and is more easily kept in repair.

All the ironwork before leaving England was immersed while hot in a composition of coal tar and asphalte, by means of which rust was effectually prevented. After erection, all the ironwork of bridges was again payed over with coal tar, which the Author believes to be the best preservative for bridge and iron work in hot countries. For ornamental ironwork, oil applied hot, or zinc paint should be used. The ironwork generally on the line, both wrought and cast, shows no more signs of deterioration than would be the case in England. The cast-iron piles, in salt water, are covered with oysters to a considerable thickness, firmly adhering to the pile, and excluding alike air and water. The rails supplied by the Ebbw Vale Company are of superior quality, and after six years' use present few signs of wear.

Amongst the items that tend to increase the difficulties and cost of railway construction in a country like São Paulo, is the haulage of materials. In May, 1861, the Author met floundering in the mud a bullock cart with eight oxen and three men, that were seven days in transporting a smith's bellows and tools from the foot of the Serra to the railway crossing at Rio Grande, a distance of under 20 miles. In 1864, about 2,600 tons of permanent way material and a small contractor's locomotive were conveyed from the foot of the Serra to the railway at San Bernardo by the public road, a distance of about 24 miles, at a cost of £11,000. The cost per ton of the haulage of the boilers and heavy pieces of machinery for the Serra engines, and of the columns and girders of the viaduct and bridges, up the railway Serra, before the inclines were at work, cannot be given with accuracy, but was very great.

Although Brazil is a slave-holding country, free labour was rendered necessary by the terms of the concession, and a scarcity of it was feared as one of the difficulties of the enterprise. Experience proved, however, that labour of one kind or other appeared as it was wanted. The hardest working and most numerous, but at the same time most disorderly, class were Portuguese and natives of the western isles. Germans were the steadiest labourers. The native Brazilian has an indisposition to work, partly from the false pride engendered by slavery, and partly from the indolence induced by the absence of incentives to work, when he can easily live in his simple way without it. Soon the solid advantages of work, in the shape of good wages regularly paid, induced numbers to leave their cabins and little plantations of bananas, beans, and Indian corn,

always, however, to return home at the planting season. They are a tractable race, easily managed with ordinary tact, appreciating kind and considerate treatment, and expecting firmness and frankness from an Englishman, but resenting keenly anything like injustice. The wages of labourers paid by the contractors during the construction of the line varied from 4*s.* 6*d.* to 6*s.* per day, when exchange was at or about par. Labourers engaged on maintenance are now paid 2*s.* 6*d.* to 3*s.* Native artisans, such as carpenters, masons, and smiths, are inferior workmen; in fact, the only artisans worthy of the name in the country are foreigners, principally Portuguese, Germans, or Italians. Englishmen were indispensable as foremen for plate-laying, &c., also as engine drivers and fitters; but too often in Brazil the Englishman 'loses his head,' and by his unsteadiness and misconduct allows the despised native or foreigner, whom perhaps he has taught all he knows, to supplant him. The wages paid to various classes of artisans are given in Appendix G (page 53); the rates have not diminished since the completion of the railway works, except in so far as influenced by the depreciation of the currency. The greatest number of men employed at one time on the line was probably about 3,500 of all nationalities and shades of colour. Most of the work was sublet in small contracts, but from São Paulo to Jundiahy much of the heavy work, including the completion of the tunnel, was sublet in considerable lengths to North American contractors of experience and means, who at that time had just completed contracts on the Serra line of the Dom Pedro Segundo railway, near Rio de Janeiro, whence they brought suitable plant and labourers trained to the work. They rendered valuable service in hastening the completion of the line to Jundiahy.

The total cost for works, stations, land, rolling stock, fixed machinery, engineering, and administration has been £24,040 per mile, and, including the extra capital to pay 7 per cent. interest during construction, £31,570 per mile. The receipts for the half-year ending June 30th, 1869, amounted to 1,262 contos of reis, and the working expenses to 447 contos of reis, being 35·46 per cent. of the receipts. It is difficult to convert these sums satisfactorily into £. *s.* *d.* sterling, owing to the depreciated and fluctuating state of the currency. Had exchange been at par, the net revenue would have been sufficient to pay 3·46 per cent. for the half-year on the total guaranteed capital; but at the current rate the equivalent in sterling is equal only to about 2·43 per cent. The depreciated currency likewise adds to the working expenses, by increasing the cost in milreis of coal and of all stores from England paid for in sterling. The satisfactory results, no doubt, are in a measure owing to the remunerative tariff; but it

must be borne in mind that, in addition to the steep locomotive gradients, all the traffic has to be raised and lowered 2,550 feet, for which service the Company are only entitled to receive the freight due to 5 miles of level line.

In Appendix I. (page 54) comparative results based on actual experience will be found, showing how the Serra inclines are costly to work per mile, and that the traffic, at locomotive rates, is conducted at a loss; but it will also appear that the traffic is worked at a considerably less total cost, and more rapidly, by the steep fixed inclines than it would have been by means of a locomotive line of 1 in 40, involving a development of 20 miles in length, on the steep slopes of the "Serra do Mar."

The Paper is illustrated by a series of Diagrams, from which Plates 5, 6, and 7 have been compiled.

APPENDIX.

APPENDIX A.

TABLE of CURVES and STRAIGHT LINES.

	Lower Locomotive Line.		Inclined Planes.		Upper Locomotive Line.				Totals.	
	Santos to Raiz da Serra.		Raiz da Serra to Alto da Serra.		Alto da Serra to São Paulo.		São Paulo to Jundiahy.			
	miles.	chains.	miles.	chains.	miles.	chains.	miles.	chains.	miles.	chains.
Curves of 20 chains' radius .	1	45	..	..	1	44	8	57	11	66
Ditto 20 to 30 ditto . . .	1	66	..	74	4	33	8	34	15	47
Ditto 30 to 40 ditto . . .	..	13	..	60	2	65	..	73	4	51
Ditto more than 40 ditto .	..	54	1	9	..	78	2	3	4	64
Total of curves . .	4	18	2	63	9	60	20	7	36	68
Straight lines . . .	9	34	2	15	20	44	17	34	49	47
Total length of each section	13	52	4	78	30	24	37	41	86	35

APPENDIX B.

TABLE of GRADIENTS on LOCOMOTIVE LINE.

	Lower Locomotive Line.		Upper Locomotive Line.				Totals.	
	Santos to Raiz da Serra.		Alto da Serra to São Paulo.		São Paulo to Jundiahy.			
	miles.	chains.	miles.	chains.	miles.	chains.	miles.	chains.
Inclines of less than 1 in 500 . .	3	4	5	14	1	30	9	48
,, 1 in 500 to 1 in 400	..	57	..	..	..	67	1	44
,, 1 ,, 400 ,, 1 ,, 300	..	11	..	55	1	49	2	35
,, 1 ,, 300 ,, 1 ,, 200	1	44	1	57	2	50	5	71
,, 1 ,, 200 ,, 1 ,, 100	1	3	4	7	6	31	11	41
,, 1 ,, 100 ,, 1 ,, 60	..	70	8	14	6	33	15	37
,, 1 ,, 60 ,, 1 ,, 50	..	..	1	13	2	56	3	69
,, 1 ,, 50 ,, 1 ,, 40	..	..	2	40	7	32	9	72
Total inclines	7	29	23	40	29	28	60	17
Level line	6	30	7	4	7	75	21	29
Total	13	59	30	44	37	23	81	46

APPENDIX C.

List of Principal Bridges.

Names of Streams, &c.	Distance from Santos.		Number of Spans.	Length of each Span.	Total Length of Bridge.	Description of Bridge.
	miles.	chains.		feet.	feet.	
River Casqueira . . .	4	8	10	50	500	Lattice girders supported on cast-iron columns.
„ Cubatão	8	38	4	75	300	
„ Mugi	12	60	3	66	198	
Mugi Viaduct	17	37	10	66	705	
			1	45		
River Grande	26	4	4	40	160	
„ Tamandatahy . .	48	17	3	40	120	
„ Tiété	54	41	6	33	198	
Juqueri	68	53	3	40	120	

APPENDIX D.

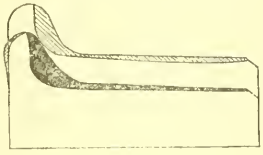
Table of Culverts and Smaller Bridges.

Section of Line.	Culverts.										Iron Bridges.			Total.
	Open.					Arched or Box.								
	2 feet.	2 ft. to 5 ft.	5 ft. to 10 ft.	10 ft. to 15 ft.	15 ft. to 18 ft.	2 feet.	2 ft. to 5 feet.	5 ft. to 10 ft.	10 ft. to 15 ft.	15 ft. to 18 ft.	26 feet Span.	30 feet Span.	40 feet Span.	
Santos to Raiz da Serra . .	..	8	5	1	..	2	4	4	1	1	4	..	2	32
Raiz da Serra to Alto . .	26	2	..	..	..	2	26	2	..	..	..	..	..	58
Alto da Serra to São Paulo .	5	10	8	2	..	56	20	9	1	1	1	..	3	116
São Paulo to Jundiahy . .	..	11	11	..	..	70	31	17	3	..	..	..	2	145
Totals	31	31	24	3	..	130	81	32	5	2	5	..	7	351

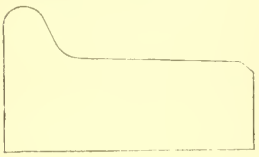
APPENDIX E.

Sections of Steel Tire,

5 feet in diameter, from leading wheel of passenger tender engine. The cylinders were 16 inches in diameter, with a length of stroke of 22 inches; the weight on the leading wheels was about 10 tons. The steel tire ran a total of 50,639 miles, while the iron tires previously used on the same engine ran about 30,000 miles.



Shaded portion shows wear of tire after having run 31,757 miles.
Dark part shows wear of tire after having been turned up second time, having run 18,882 miles.

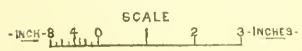


Original section of tire.

Section after having run 31,757 miles.

Section after having been turned up second time.

Section after having run 18,882 miles.



APPENDIX F.

SCHEDULE of LOCOMOTIVES and ROLLING STOCK.

	Number.	Total.
LOCOMOTIVES.		
Passenger and mixed engines	12	
Goods engines	6	
		18
CARRIAGE STOCK.		
First class carriages	6	
Composite ditto	12	
Second class ditto	1	
Mail and second class ditto	3	
Prison van	1	
Third class carriages	15	
Passenger break	5	
		43
GOODS STOCK.		
Covered wagons	126	
Break vans	20	
Open trucks	55	
Cattle ditto	7	
Timber ditto	6	
Carriage ditto	2	
Horse box	0	
Poultry van	1	
		217
SPECIAL STOCK.		
Ballast wagons	23	
Serra breaks	10	
Serra rope wagon	1	
Travelling crane	1	
		35
Total	..	313

APPENDIX G.

TABLE of WAGES during CONSTRUCTION.

Exchange taken at par = 27*d.* per milreis.

	Wages. From. £.	*s.*	*d.*	To. £.	*s.*	*d.*	Per
Labourers (Native or Portuguese)	0	3	9	0	5	6	day
Gangers „ „	0	6	0	0	9	0	„
Masons „ „	0	6	6	0	10	0	„
Carpenters „ „	0	6	6	0	10	0	„
Blacksmiths „ „	0	6	6	0	10	0	„
Miners „ „	0	5	6	0	6	6	„
English gangers or foremen	0	12	0	1	1	0	„
English fitters, smiths, painters, engine-drivers, &c.	14	0	0	18	0	0	month

English workmen, such as fitters, smiths, &c., are generally engaged for three years, with a free passage home at the end of the term, or before if invalided.

APPENDIX H.

COMPARATIVE STATEMENT of RECEIPTS and EXPENDITURE for the Half-year ending June 30, 1869, showing the Loss per mile in working the Inclined Planes at the Locomotive rates.

TOTAL RECEIPTS and EXPENSES.

	Milreis.
Receipts	1,262,752 840
Expenses	447,781 043
Net Earnings	814,971 797

LOCOMOTIVE LINE, 81½ miles open.

	Milreis.
Receipts per mile open	14,598 299
Expenses per mile open.	4,298 226
Net earnings per mile open . .	10,300 073

SERRA, 5 miles open.

	Milreis.
Receipts per mile open	14,598 299
Expenses per mile open.	19,495 122
Loss per mile open	4,896 823

APPENDIX I.

COMPARATIVE STATEMENT showing the COST of WORKING a given Traffic up and down the SERRA DO MAR, First, by Steep Inclines worked by Fixed Engines and Ropes; and, Secondly, by Locomotives on a Gradient of 1 in 40.

1. STEEP INCLINES.

Gradient 1 in 9·75; total length 5 miles.
Number of inclines four; total height 2,250 feet.
Speed of running 6 miles per hour.
Coal consumed 1 ton per hour for four engines.
Number of cars in train three; trains per hour four.
Total weight of train, including break, say 38 tons.

Average Daily Work [H.P. exerted 170 × 4 = 680 H.P.].

Say, five hours running, two hours allowed for getting up steam, &c. Total, seven hours in steam.

Say 54 goods wagons	up, and	54	down, per day.
„ 6 passenger carriages	up, „	6	down, „
60 vehicles	up, „	60	vehicles down.

Divided into twenty trains up and twenty trains down of three wagons each, to which must be added special safety break attached to each train.

Engine miles 20 × 5 = 100. Train miles 20 × 5 × 2 = 200.

Cost of Performing above Work per Day.

			£.	s.	d.		£.	s.	d.
Coal, 1 ton per hour	× 7 = 7 tons	at	2	5	0	=	15	15	0
Oil, 1 pint ,,	× 7 = 7 pints	at	0	1	0	=	0	7	0
Tallow, 1 lb. ,,	× 7 = 7 lbs.	at	0	0	7	=	0	4	1
Other stores 4s. ,,	× 7	at	0	4	0	=	1	8	0
							17	14	1
Salaries and wages connected with running, per day .							12	0	0
Total running expenses							29	14	1
Repairs and renewals, including engines, boilers, ropes, pullies, &c., 100 engine miles, at 2s. . . . . =							10	0	0
Total tractive power							39	14	1
Proportion of repairs of carriages and wagons, 4s. per mile per day, × 5 miles . . . . . =							1	0	0
							40	14	1
Maintenance of way and works, 18s. per mile per day, × 5 . . . . . =							4	10	0
Total cost per day							45	4	1

2. Locomotive Line.

Gradient 1 in 40.
Length 20 miles.
Speed of running 10 miles per hour.
Coal consumed 6 lbs. per H.P. per hour.
Weight of engine and tender 45 tons.

Assumed Daily Work.

Say 55	goods wagons	up, and 55	down per day.
,, 5	passenger carriages	up, ,, 5	down ,,
60	vehicles	up, ,, 60	vehicles down.

Cost of Performing above Work per Day.

Five goods trains, each eleven wagons, weighing 110 tons + 45 tons, weight of engine and tender, = 155 tons, or 347,200 lbs. gross load to be lifted 22 feet per minute, at a speed of 880 feet per minute. Then—

347,200 lbs. × 22 feet = 7,638,400
155 tons × 12 lbs. × 880 = 1,636,800

9,275,200

$$\frac{9,275,200}{33,000} = 281 \text{ H.P. on ascent.}$$

Passenger Train.

One train of five cars weighing, say 7 tons each = 35 tons + 45 tons, weight of engine and tender, = 80 tons, or 179,200 lbs. gross load, to be lifted 30 feet per minute, at a speed of 1,188 feet per minute, or 13½ miles per hour. Then—

179,200 lbs. × 30 feet = 5,376,000
80 tons × 14 lbs. × 1,188 feet = 1,330,560

6,706,560

$$\frac{6,706,560}{33,000} = 203 \text{ H.P. on ascent.}$$

2. Locomotive Line—*continued.*

Consumption of coal taken at 6 lbs. per H.P. per hour.

Goods trains 281 H.P. × 2 hours × 6 lbs. × 5 trains =	16,860	for five up goods trains.
Passenger train 203 H.P. × 1½ hour × 6 lbs . . =	1,827	for one up passenger train.
	18,687	
	2,240	= 8⅓ tons of coal on ascent.

Train miles on ascent 20 × 6 = 120 train miles.

		Tons.
18,687 lbs ÷ 120 = 155 lbs. per train mile		8·3
Lighting up three engines, say = 2,240 lbs. = per day . .		1·0
Standing in steam six hours at 100 lbs. per hour	600 lbs.	
Descending, taken as standing in steam twelve hours at 100 lbs.	1,200	
	1,800 =	0·7
Total consumption of coal per day		10·0 tons.

Total train mileage 240.
Allowed for standing 48 = 288 engine miles.

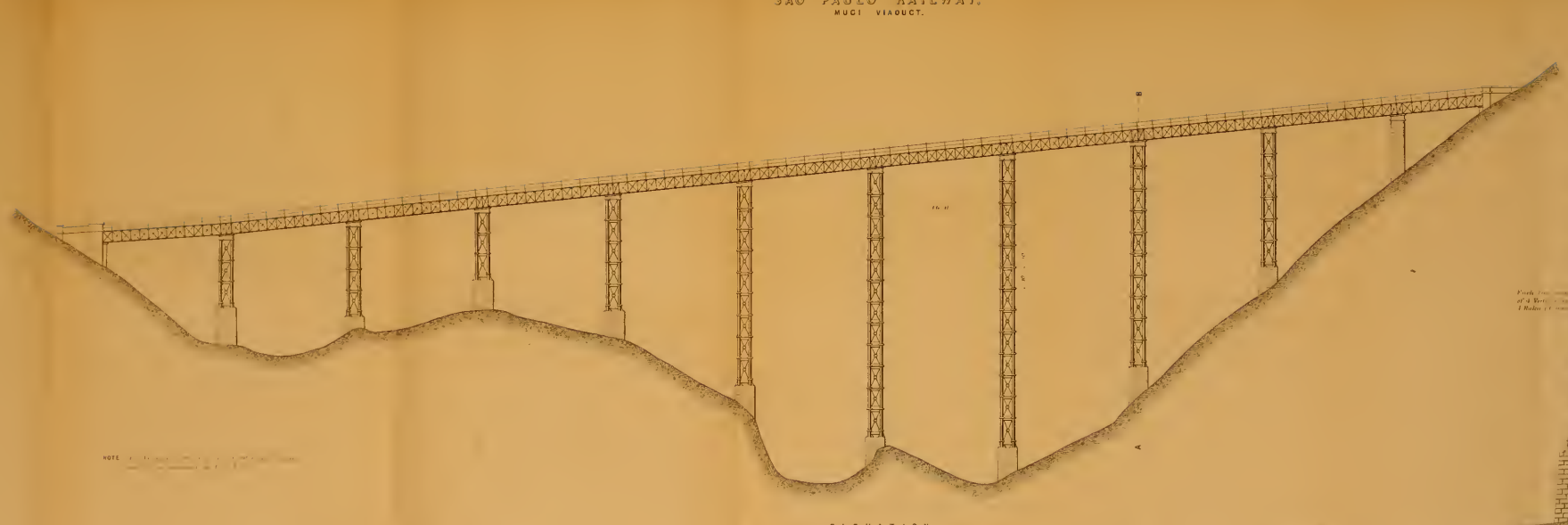
			£.	s.	d.	£.	s.	d.
Coal per day	10 tons	at	2	5	0	=22	10	0
Oil	288 miles × 0·60 pint = 18 pints; 18 pints	at	0	1	0	= 0	18	0
Tallow	288 miles × 0·50 lb. = 15 lbs.; 15 lbs.	at	0	0	6	= 0	7	6
Other stores 288 miles × ¾d.		at	0	0	0¾	= 0	18	0
						24	13	6
Salaries and wages connected with running locomotives, say . . .						7	4	0
Total running expenses						31	17	6
Repairs of locomotives, say 9¾d. × 288 engine miles per day . . .						11	14	6
Total tractive power per day						43	11	6
Proportion of repairs of carriages and wagons, 4s. per day per mile × 20 . . . . . =						4	0	0
						47	11	6
Add extra station for water and passing place per day, say						1	10	0
						49	1	6
Maintenance and renewal of permanent way and works, 18s. per mile per day × 20						18	0	0
Total cost per day						£67	1	6

SÃO PAULO RAILWAY.

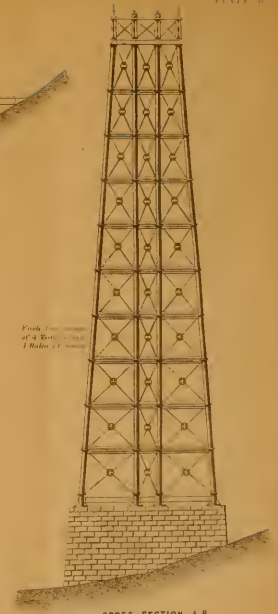
RIO OF SANTOS
I. DE SÃO AMARO
SANTOS
Cubatão
Mogy
Rio Cubatão
Rio Mogy
Piaçaguera
Rio Piaçaguera
Rio Pereque
Rio Perequezinho
Rio Jurubatuba
Rio Guarahu
Rio Guarahuzinho
Rio Estrella
Rio Pinheiros
Rio Tamanduatehy
Rio Jaguary
Rio Juqueri
Rio Atibaia
Rio Jundiahy
Rio Capivary
Rio Piracicaba
Rio Tieté
Rio Grande
Rio Barbado
Rio Santo Anastacio
Rio Jaguary
Rio Anhumas
Rio Quilombo
Rio Jaguary
Rio Jundiahy
Rio Capivary
Rio Piracicaba
Rio Tieté
Rio Grande
Rio Barbado
Rio Santo Anastacio
Rio Jaguary
Rio Juqueri
Rio Atibaia

SÃO PAULO RAILWAY.

MUGI VIADUCT.

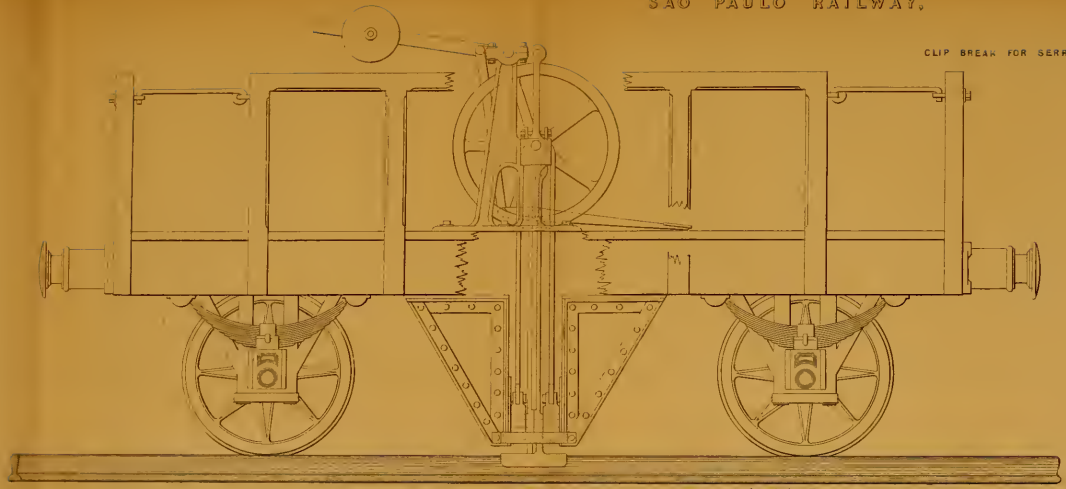


ELEVATION.



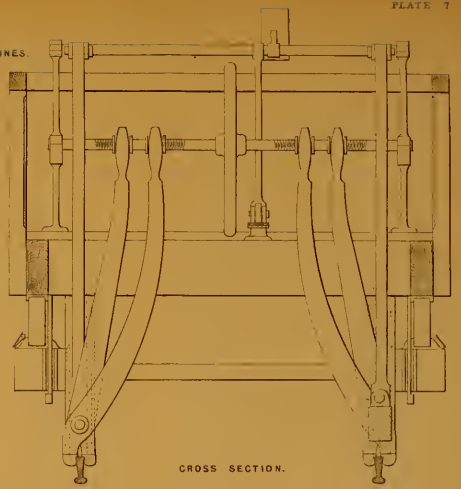
CROSS SECTION, A B

CLIP BREAK FOR SERRA INCLINES.

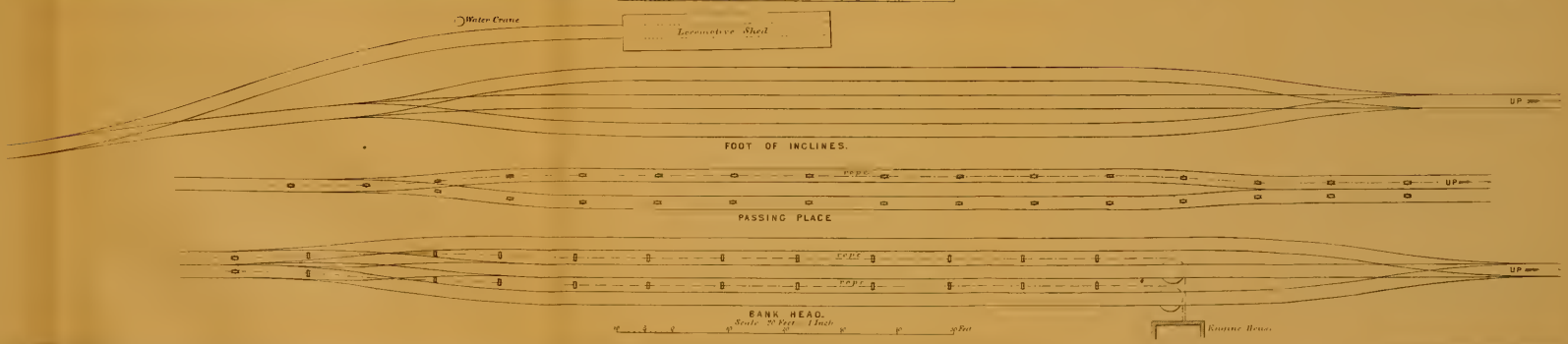


ELEVATION.

Scale ½ Inch = 1 Foot



CROSS SECTION.



Mr. Brunlees said that, in the desire to open the first section of the line, which extended from Santos on the sea coast to the bottom of the Serra, as soon as possible, the designs were somewhat hurriedly prepared. In the case of the viaduct over the Cubatão river the spans were made too small, for, soon after it was erected, a flood occurred, which brought down great quantities of driftwood from the steep hill-side, and this, accumulating behind it for a distance of about 2 miles, caused the viaduct to give way. That was the principal misfortune experienced in connection with these works. A viaduct with four spans of 75 feet each was erected in the place of one with six spans of 40 feet each, and that had performed its duty without failure. When the inclines were first laid out, it was said he was becoming old-fashioned in his engineering, and that, instead of advancing, he was going backwards in employing fixed engines and ropes for working the traffic; but he had no alternative. He undertook to make the line for a fixed capital of £2,000,000, and the plans had to be adapted to the circumstances of the case. If a locomotive line had been made (he was referring to ten years ago), the whole of the capital would have been expended in reaching the top of the escarpment, called the Serra do Mar, so that fixed engines and ropes became a necessity. Had a similar work to be undertaken now, he would probably try to get a gradient of 1 in 14, and employ the centre rail system. In a place such as the Serra, where in about four months of every year there was a rainfall of between 14 feet and 15 feet, the shortest possible line was important on the score of maintenance; and that could not be obtained on any other system than that of rope traction. In the Paper a comparison was made between the cost of working a locomotive line with a gradient of 1 in 40, and the cost of the rope system on the gradient of 1 in 9¾. Mr. Brunlees thought that, on the locomotive line, somewhat less coal would be used than was stated by the Author; and that, instead of the cost amounting to £67 per day, it would not have exceeded £58, thus reducing the saving by the rope system to £13 per day, instead of £22 per day as stated in the Paper. That was, however, a small matter when compared with the fact, that the interest of the additional capital necessary for a locomotive line would alone have amounted to about £200 per day.

Since the Paper was written, at the latter end of 1869, a rope broke when a goods train was about 100 yards from the top of one of the inclines. The breaksman immediately applied the clip break, and the train was thus brought to rest in a distance of 66 feet. The rope was then spliced, and in three hours the traffic was resumed. The break, as shown in cross section on Plate 7, was in action; but, when the train was running, the jaws were raised a little above the level of the rail, and were held there by a weight.

When it had to be applied, as in the case of the rope breaking, the breaksman first of all put his foot upon the treadle; this raised the weight, and allowed the jaws to fall down until they were below the level of the rail: the wheel, acting on a right and left-handed screw, was then turned, and the jaws gripped the rail. Before Mr. Brunlees had had an opportunity of trying this clip break, he felt a good deal of concern and anxiety about the working of the inclines; but this was set at rest as soon as the break was actually tried, and he believed it would be equal to any emergency that could occur.

To save labour, more especially skilled labour, which in a country like Brazil was scarce and expensive, the piers of the Mugi viaduct were designed to consist of a series of cast-iron columns, each column being composed of a number of pieces of equal lengths; by this arrangement every piece would fit any part of a column throughout the whole of the piers of the structure. The Contractors adopted a very economical plan of putting these pieces in place. They stretched a wire rope from one side of the opening to the other; and by that means each length was lowered into its place, and the bolts were put in and fixed without any skilled labour. The girders were hoisted by a crane, and were carried forward from one end, the whole structure being erected without scaffolding. The use of the rope for swinging the materials into place was not new. About thirty years ago, Mr. Adie adopted the same means for lowering the stones in the open cutting of the Chorley tunnel. All the bridges on the line were nearly of the same kind, and he found that nothing was more convenient for shipping, for transmission up the country, and for erection, than bridges of the construction he had adopted.

Much credit was due to Mr. Fox for the able way in which he had laid out the line and superintended the execution of the work. The difficulties were great throughout, particularly in surmounting the precipitous Serra. As an instance of the delay in getting over the ground, he might mention that the first time he visited São Paulo, in 1860, it took him two days, of twelve hours each, to pass from the bottom to the top of the Serra. It was not walking, but scrambling the whole way; and for a considerable distance Mr. Fox had to deal with the same kind of country. In all his experience, Mr. Brunlees had not seen a tract of country which presented so many physical obstacles to the formation of a railway as was the case with this line.

Mr. J. J. Aubertin remarked that he had acted as the Company's Superintendent during the whole period of the construction of the São Paulo railway; and that from the early part of 1860 till the middle of 1868 he was resident in the province. Of the three Anglo-Brazilian railways, the Pernambuco, the Bahia, and the

São Paulo, he thought the latter was pre-eminently the most important, not only from the difficulties of construction owing to its great characteristic, the Serra, but also from the importance of the province which the railway was destined to open. The peculiarity in the constitution of the Company consisted mainly in the concession granted by the Brazilian Government. It was desired to invite foreign capital and experience into the country for the purpose of making railways. A guarantee of 7 per cent. was, therefore, offered, but at the same time the capital was fixed at the arbitrary sum of £2,000,000 sterling. One reason for that was, that what was done for one province might hereafter be expected to be done for another; therefore it was deemed prudent to limit the expenditure within a certain amount. Accordingly, in carrying out the line from Santos to Jundiahy, if the Company spent less than that sum, the Government would have the benefit in regard to the guarantee; and if more was spent, it would be at the Company's risk. The first duty of the engineer was, therefore, to get to the end of the work for the least possible sum; and the Government, of course, had the right to appoint a fiscal engineer to see what work was done per month, and what was paid for it. He thought that there was great advantage in the presence of the Fiscal, inasmuch as he was equally interested with the Company in seeing that everything was properly carried out; and, therefore, when any directions were given to the contractors, they came with the double authority of the Resident Engineer and the Government Fiscal. During the progress of the construction there were four changes of the Fiscal; but he freely confessed that all behaved exceedingly well and fairly to the Company; and their assistance was advantageous, not only during the whole period of construction, but after the line was finished, as whatever rules were laid down for the working of the traffic were accepted by that officer on behalf of the Government. Again, another benefit was experienced in taking the monthly accounts of traffic receipts and payments, because, if the Government guaranteed 7 per cent. on the capital, they had a right to see what the Company received for gross traffic; and every month there was a strict audit of the receipts and expenditure of the line, by the representatives of the Government and of the Company. The only disadvantage that could arise from the constant presence of the Fiscal on the works was, perhaps, a disposition unduly to interfere; but that was best met by perfect openness and candour on the part of the engineer; and so long as an English engineer showed himself to be equal to his position, and took his own ground in a foreign country with firmness and candour, he need have little fear of undue interference with his proceedings.

Another point he would allude to was the settlement of the final accounts with the Government. It might be worth bearing in

mind that these concessions were exclusively Brazilian; they were not made to English companies, but to certain eminent Brazilians. As, however, the Government was not very practical in the matter of railways, England was resorted to both for the money and the science to make them. Certain theoretical conditions were laid down which, when brought to the test of practice, proved inapplicable. The result was that it was found necessary to propose some modifications, and Mr. Brunlees, in his capacity of Engineer-in-Chief, did suggest one or two most important modifications, by which the Government was induced to vary the original concession by an imperial decree; but the interpretation of the decrees, in connection with the concession, remained to be determined, in respect of the obligations of the Company and the settlement of the capital account. The perfect good faith of the Government had never been questioned; but theory and practice did not always go together, and what was understood as a matter of common sense was not always accepted by the legal and sceptical mind.

The grand characteristic of the line was the Serra, which consisted of a great land-cliff covered with primeval evergreen forest, up which, to a height of 2,600 feet, or half a mile, the railway was carried. There was no other way of getting into the real province except by surmounting this great cliff, which rose abruptly, 9 miles in a direct line from Santos, but 12 miles or 14 miles by the railway. The inclines were decided upon for the reasons stated in the Paper; and as early as 1856, Mr. Fox was despatched to Brazil to trace the line through the Serra. He was accompanied by Mr. James Bolland, and aided by him Mr. Fox set out the line, so as to conduct it from the flats near Santos to the tableland of the province. That work in itself represented a difficulty which was aggravated by the atmospheric peculiarities of the country. The Serra, which in some places rose to a height of 5,000 feet, condensed the moist winds from the sea, and there was either rain or fog on ninety days out of one hundred. The rains were very different from what were experienced in this country; they descended in floods, which could scarcely be conceived by those who had not experienced them. When the condensation of the vapour was not sufficient to produce rain it caused fog; and engineers knew that in such a state of the atmosphere it was impossible to use surveying instruments. Then again the whole of the line was traced upon the cheek of the spurs, so that the engineers who laid it out had but slight footing, not only in mounting 1 in 10, but on the hill side the declivity of about 1 in 4. That spot used to be called the key of the railway; but he regarded it rather as the lock, and being so near the beginning of the line, it locked up nearly the whole length. The public roads up the other part of the Serra were of little or no use for the conveyance of materials.

He thought the present inclines afforded, for many reasons, the best mode of surmounting the Serra. Even had the money sufficed for the construction of a flatter line, he thought the comparatively short length of this portion of the line was an advantage, as there were fewer banks and cuttings to give way. The only other Serra to compare with this, that he was acquainted with, was that on the Dom Pedro Segundo railway, which was a locomotive line, with a gradient of about 1 in 33, a length of 15 miles of which was over a Serra with very many tunnels. He had heard Major Ellison, the Engineer of the line, say that if he had again to go through that description of country, he would get over the difficulty by means of inclines rather than by prolonging the works to secure a locomotive line. Even if the capital had sufficed to make a locomotive line, it was a question whether for working the traffic it was not better to have inclines. The ruling gradient through this rugged country was 1 in 40, and as the Serra inclines were 1 in 10, it would have required the line to be prolonged four times to get that gradient; and the Serra was so formed that, if a locomotive line were made, it was doubtful whether it would be cheaper per mile than the inclines. The Author of the Paper had calculated the cost of a line to the top of the Serra, on a gradient of 1 in 40, at £1,500,000, instead of £500,000, which was the sum spent; and that added to the cost of maintenance of the additional embankments, which would have been enhanced by the heavy rains acting upon them, would have placed the Company in a much worse position financially.

Although the Author stated that the working of the Serra was 50 per cent. more expensive than a locomotive line, yet the figures in the Appendix to the Paper proved that whereas the Serra cost £45 per day in its present working, it would have cost £67 per day if worked as a locomotive line. Mr. Brunlees had remarked that if he had now to construct this line, he would probably introduce the third rail on Mr. Fell's system. It was not for him to dispute that opinion; but he thought as the Serra was worked, there was a freedom from the strong impact of the locomotive passing and rumbling up and down the banks built upon the hill side; the mere traction of the wagons by means of the rope gave no shock at all to the embankments; and an instance had even occurred of a man on the line being overtaken by a train from not hearing it descending behind him. There was the change at the bottom and the top of the incline, but that did not interfere with the working capacity of the Serra. Every hour four trains of three wagons passed from the top and bottom, each carrying 7 tons net, being a total of 168 tons an hour up and down the Serra, or in a day of ten hours 1,680 tons of goods. Taking the year at three hundred working days, this gave 500,000 tons annually as the working

capacity of the Serra by the existing system. The present traffic did not reach 100,000 tons. In 1869 it amounted to 77,500 tons; but when it was 100,000 tons, as he believed it might shortly be, that would only be one-fifth the capacity of the Serra, and the Government would not (with currency at par) have one farthing to pay to make up the guarantee of 7 per cent. The above quantity of goods and the passenger traffic would yield that amount of interest not only upon the £2,000,000 of capital expended on the line, but also upon the £650,000 paid as interest during its construction; so that if the full carrying capacity of the Serra were ever exerted, it would give a return of no less than 35 per cent. upon the amount of capital. That was a moderate calculation of the capacity of the Serra, because he had the authority both of Mr. Brunlees and of Mr. Fox for saying, that the wagons could be passed up and down, with perfect safety, in three-quarters of an hour instead of one hour. These were the general aspects presented by the undertaking, and he thought, looking to the future prospects of the province, what with its cotton, its corn, its coffee, its wine, and its tobacco, the future of the railway was certain to be a profitable one to the shareholders, and that it would more than realise all that had been anticipated from it.

Mr. C. B. Lane said, he was not previously aware that a railway had been projected in this province so far back as thirty years ago, and that the late Mr. Robert Stephenson was consulted on the subject. So far as his own knowledge went, this railway was first promoted by the Baron de Mauá—a man to whom, more than any other, the physical development, not only of his own country within the last twenty-five years, but also of other wide districts of the continent of South America, was due. To the Baron de Mauá, he believed, many parts of South America, as well as Brazil, were indebted for the introduction of railways, gas lighting, steam navigation, and other important advances in physical prosperity. So far back as 1852, Mr. Robert Milligan, M. Inst. C.E., was sent by the Baron de Mauá to examine the ground for a railway in this province of Brazil, and he made detailed surveys and sections from the top of the Serra to Jundiahy; and the ground selected by him had scarcely been deviated from in the construction of the line as ultimately carried out. In 1854, Mr. Milligan brought these plans and sections to him, and they conjointly made an estimate of the cost of a line from the top of the Serra to Jundiahy. But Mr. Lane pointed out that a fragmentary scheme of that kind was not likely to be taken up in England; and he recommended that an examination should be made as to the best means of overcoming the difficulties of the so-called Serra—for Serra it certainly was not, in the proper sense of that term, being not so much a mountain chain, as a great uplifting of the continent,—and thus

placing the produce from the interior in direct contact with the shipping in the port of Santos. Mr. Milligan was to have arranged to carry out these examinations; but the Baron had other duties for him to attend to. These he zealously fulfilled for many years, and ultimately was from broken health obliged to retire. Mr. Lane felt sure that in making these remarks, to connect the name of Mr. Milligan with the early history of this railway, he would not be considered as wasting time, but merely discharging the duties of friendship and of justice.

About 1854-55 the matter was put into Mr. Brunlees' hands, and Mr. Fox was sent to Brazil charged with the duty of examining what looked very simple as shown by a few lines on paper, but was in reality a piece of country of extreme difficulty, being very rugged and steep, and covered with interminable forest and underwood. In due time Mr. Fox completed the arduous work of the survey, and had since carried out the works as Mr. Brunlees' Chief Resident Engineer. In 1856-57, the Imperial Government placed in Mr. Lane's hands the plans, sections, and reports of Mr. Brunlees to the promoters, and after careful consideration, he felt it his duty strongly to recommend their adoption. The problem which Mr. Brunlees had to determine was, whether it was better at once to face the Serra, and mount it by means of the four steps, or to make a line 26 miles or 27 miles long, passing along the face of the great escarpment with an endless succession of sharp curves, constantly recurring deep cuttings or tunnels, through its lateral spurs, and viaducts of great height and large spans over the intervening gorges. Mr. Brunlees arrived at the conclusion, that the plan finally adopted was the best, and in that view Mr. Lane entirely concurred. To have carried out a line contouring and gradually ascending this great escarpment would (judging from the cost of the existing 5 miles on the Serra) have cost £100,000 per mile; the difference in cost would then have been so enormous, that the result would have been a commercial failure.

Mr. Vignoles, in his inaugural address as President, had given good advice to engineers on that topic; for Mr. Lane believed that the chief duty of an engineer, especially in countries where the population was thinly distributed, and large districts had to be traversed to collect a remunerative traffic, was to make his works commercially successful. That result had been attained by the plan adopted in the case of the São Paulo railway. The works of the line had been so fully described in the Paper, that he had not much to say on that branch of the subject. Looking to the fact of the Cubatão bridge having been carried away, he agreed with Mr. Brunlees, that the providing of ample way was of the first importance; indeed, it was scarcely possible for any engineer, unacquainted with this Serra and its climate, to form an adequate

idea of what the floods were. The earth-works and retaining walls on the Serra were necessarily of large dimensions; amongst the works of art, the viaduct crossing the great gorge of the Mugi on the Serra was the most noteworthy. He concurred with Mr. Fox as to the importance of having all the castings for the permanent way made to one model; simplicity, while always desirable, was especially so where works had to be executed under such circumstances as had been described. Mr. Brunlees, too, deserved credit for having abandoned the custom, so long followed in England, of placing the wedges of double-headed rails upon the outside instead of upon the inside.

In conclusion, it only remained to congratulate Mr. Brunlees, on having adopted the principle which Mr. Lane believed to be the best, for solving the difficult problem presented to him, and on being instrumental in producing for his employers and for Brazil a great 'commercial success.'

Mr. Hemans, Vice-President, remarked that the Paper embraced the question, as to what system ought to be adopted for surmounting steep inclines. The example of Mr. Brunlees, and his large experience in the matter, should have weight with the profession, especially when it was known that he was the Engineer of the Mont Cenis railway, where an entirely different system had been followed to that adopted in the province of São Paulo. He thought a wise discretion had been exercised in not laying out an additional £1,000,000 of capital in order to obtain a locomotive line; but the subject demanded further discussion, and in his opinion Mr. Fell's system of working inclines was worthy of consideration. It must be observed that the rope system was open to certain *primâ facie* objections, which ought to prevent its being adopted, if it was possible to do otherwise. For instance, although Mr. Aubertin had shown that goods could be taken over these inclines to a large aggregate amount in a year, still the real result was the rather rigid limit of three wagons in each train four times in the hour. It had been said that that could be extended to five trains in the hour, if necessary, which would be fifteen wagons instead of twelve. Now if the traffic came in such steady proportion, that it could be conveyed by trains of that nature every hour, there was nothing more to be said; but it was well known at what irregular intervals and in what irregular quantities traffic accumulated, and it was an embarrassing matter to be tied, as was the case with the rope and the atmospheric systems, to a limited number of trains in an hour, and those of limited capacity. Then, again, the comparison with locomotives had not been made on correct grounds. A gradient of 1 in 40 had been assumed, and on that gradient it was calculated to take ten trains of goods and one of passengers per day, at an expenditure of 6 lbs. of fuel per H.P.

per hour, and at a total cost of £67 1*s.* 6*d.* per day. Although Mr. Brunlees had corrected those figures, Mr. Hemans would observe that a fairer calculation would have been to assume a gradient of 1 in 20 for locomotives, but merely as a comparison of power, as probably, with the limited capital, it might not have been possible to make such a gradient in this case. With a gradient, however, of 1 in 20, and the high consumption of 6 lbs. of fuel per H.P. per hour, as stated in the Paper, he arrived at different results. For instance, the resistance to a train, on an incline of 1 in 20, proceeding at a speed of 10 miles an hour, or 880 feet per minute, with an engine of 359 H.P., would be 13,458 lbs. The consumption of coal would be, for ten goods trains and one passenger train, 10½ tons per day, for lighting engines about 1½ ton, and descending about 1 ton, or a total of 13 tons per day, instead of 10 tons according to Mr. Fox's calculation. In the remainder of the Author's comparisons, he found figures put down for locomotive expenses which ought not to have been adopted, in order to show the superiority of rope over locomotive traction. One item was 9¾*d.* per running mile for the repairs alone of locomotives, whereas, on reference to Mr. J. T. Harrison's tables,[1] it would be found that 9¾*d.* per running mile was more than the whole cost of locomotive expenses in this country, including fuel: therefore that figure could not be maintained. He thought the comparison should rather stand thus:—

	£	*s.*	*d.*
Coal per day, 13 tons, at £2 5*s.* . . . . . =	29	5	0
Locomotive expenses, excepting fuel, 220 miles, at 8*d.* . . =	7	6	8
Carriages and Trucks, 220 miles, at 4*d.* . . . . . =	3	13	4
Maintenance, 220 miles, at 8*d.* . . . . . =	7	6	8
Total per day . .	£47	11	8

instead of £67 1*s.* 6*d.* Besides, it was far from certain that locomotives might not be adapted to work on an incline of 1 in 9¾ even without a middle rail. On the 15th of February, 1870, Mr. Fairlie's engine, 'Progress,' weighing 54 tons, took a load of 530 tons up an incline of 1 in 75, at a speed of 9 miles an hour, developing 20,518 lbs. tractive force and 500 H. P., the adhesion being about ⅙th. That showed that, under proper conditions, locomotives might be made to take themselves and a load even up such inclines as 1 in 10, though he did not mean to say that would give an economical result. On the Mont Cenis railway there was ample adhesion, and no chance of the trains slipping; and any number of trains per hour might be run with a lighter engine than Mr. Fairlie's. It had been stated, both by Mr. Fell and by Mr. Longridge, that the expenses on the Mont Cenis line were at the rate

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx'x., p. 344.

of only 4*s.* 6*d.* per train mile, after deducting the cost of management. If that rate was applied to the 220 miles on these inclines, the cost would be £45 per day, which was within a very small sum of that of the rope system. Therefore, as the expense of the middle rail would be small on the length of line comprising the Serra, he thought, if another instance of this kind occurred, the middle rail would be preferable to the rope. With regard to the cost of construction, no one, he thought, would say that the greater length of line should have been made in this case; but as the comparisons between rope and locomotive power in the Paper were obviously incorrect, they ought not to be allowed to pass unnoticed.

Mr. J. M. Heppel was of opinion that, considering the financial position of the Company, nothing could have been wiser than the course adopted in concentrating the heavy works into the smallest possible compass. It was just possible that if the principle which had been so successfully carried out on the Mont Cenis line had been sufficiently understood at the time, it might have been found applicable with advantage; but having looked carefully into the Paper, he was inclined to think that the Engineer could not have selected a better system than that actually adopted for these inclines. The only thing he was not previously aware of was, that whereas the inclines were laid out at 1 in 10, the natural face of the escarpment approached something like 1 in 4. Mineral lines were worked with fixed engines at 1 in 5 or 1 in 6; and if improvements were to be sought for, he would suggest whether a steeper gradient than 1 in 10 might not have been adopted on this section of the line.

Mr. Wm. Lloyd expressed a doubt whether, in this particular instance, a locomotive incline would not have been preferable. Engine manufacturers had stated their willingness to construct, on their own responsibility, engines competent to work trains upon a gradient of 1 in 15; and by the section of the incline it would seem, that by taking out the level portions, or bank heads, such a gradient might have been obtained without any great extension of the incline, as the length of incline would only have been increased from 5 miles to 7½ miles. An engine to work such an incline would be 68 tons in weight, and would haul a load of 145 tons exclusive of its own weight. Of such weight ¾ths would be paying load if suitable stock were used. If such an engine could be produced, and experience satisfied him that it could, it would, by making one trip per hour, convey up the incline 1,450 tons in a day of ten hours, so that 6,000 tons of weight could be raised in a day by employing the same number of engines as were used on the incline instead of 2,000 tons as stated in the Paper. The liability of the rope breaking had been experienced in similar instances abroad; with a locomotive line this would not occur.

Mr. Lloyd had been furnished by Mr. J. W. Featherstonhaugh with some particulars relative to a mineral railway to the port of Pomaron, Portugal, constructed by him in 1861. The gauge was 3 feet 6 inches; the rails weighed 36 lbs. per yard, and were laid on sleepers placed 2 feet 6 inches apart from centre to centre. The length of the line was 13 miles, and out of this distance there were gradients of from 1 in 28 to 1 in 40 for an aggregate length of 8 miles, and of 1 in 19 for $\frac{3}{4}$ of a mile. There were also curves of from $2\frac{1}{2}$ to 9 chains' radius. Tank-engines were employed, with four coupled wheels, each 2 feet 3 inches in diameter. The cylinders were 10 inches in diameter, with a length of stroke of 15 inches. The weight of the locomotive when in working trim was 12 tons 7 cwt., and the steam was maintained at a pressure of 120 lbs. The wagons weighed when empty 1 ton 7 cwt. each, and carried 4 tons 17 cwt. of minerals, or 78 per cent. of paying load. The engines conveyed up the gradient of 1 in 19 a gross load of 26 tons, exclusive of their own weight, at a speed of 5 miles per hour. The mineral traffic was from 150,000 to 180,000 tons per annum. The average cost of working was less than 1*s.* per train mile.

Dr. W. Pole would suggest that, in cases where it was necessary to use inclines steeper than could be worked with locomotives, it might be desirable to consider the applicability of the atmospheric system. No doubt there might be good reasons why the rope was preferable in the present case; but it must be remembered that the 'rope of air' claimed important advantages over the rope of hemp. The system had failed in England, for reasons easily accounted for;[1] but it had always been admitted, even by its strongest opponents, that there were cases where it might be advantageously applied. Mr. Bateman had lately suggested one, of great magnitude and importance, and it was possible that very steep railway inclines might be in a similar category.

Mr. Bramwell observed it had been asserted that an engine could be constructed capable of taking its own weight and 145 tons of load up an incline of 1 in 15; but it was said that the engine to be employed to do this must weigh 68 tons, or nearly half the load it could haul behind it. Now having regard to the fact of the enormous percentage of useless weight such an engine would bear to the load it could draw, he thought that even if there were considerable loss of power and difficulty attendant upon the rope system, nevertheless that system was preferable to the use of a machine which weighed 50 per cent. of the useful load it could move. And looking at the further fact that it was admitted the rope system gave carrying capacity five times in excess of the requirements, so that no restriction of traffic resulted from its use,

[1] *Vide* "Life of Robert Stephenson." By Jeaffreson and Pole Chap. XIV.

he thought a wise discretion had been exercised in working these inclines without the use of locomotives.

While agreeing in the use of ropes to stationary engines, he must protest, however, against those engines being called high-pressure engines. It was a misnomer. They were in fact not high-pressure engines, but non-condensing engines working at a low pressure (30 lbs. to the square inch). If there was a wasteful machine it was a non-condensing engine working at a low pressure. He hoped that the cylinders of 26 inches in diameter would be taken out and be replaced by others, say of 14 inches in diameter worked at a really high pressure with its resulting economy.

The break van introduced on this line was worthy of remark. It was stated that it would arrest, in a distance of 30 yards, a train of 28 tons weight going at a speed of 10 miles an hour down a gradient of 1 in 10. He found that to do this the break must exert nearly 4 tons of retarding force. This great force was obtained by the lateral pressure of the clip, and not by the friction representing a percentage of the weight of the wagon on the rails. With such a construction, therefore, there was no need to have a heavy break wagon. The one employed weighed probably only 4 tons to 5 tons, or about one-sixth of the total load of the train; while if an ordinary break wagon had been used, even if as high a co-efficient of friction as one-fifth had been taken, that wagon, or rather those wagons must have weighed nearly 20 tons—a most serious drawback when it was considered that such a weight would represent five-sevenths of the whole weight of the train. He thought the success of this break demanded investigation as to how far it could be applied for ordinary use on railways generally.

Mr. Hawkshaw, Past-President, said that in discussing the respective merits of rope traction and locomotive traction an important element had been left out of sight, viz., £50,000 a year, the interest upon a million of money. In Brazil or other similar countries, where the money had to be raised in England, it was important to save the expenditure of an additional million of capital; and in doing so the Engineer had in this case, in his judgment, done wisely. Whether or not locomotives could be constructed to work these inclines at less cost than had been stated for the rope, it would be found, if the zig-zag locomotive inclines had been carried out upon this precipitous cliff, that an additional expenditure of £50,000 a year would have been incurred as a preliminary matter.

With regard to the possibility of the rope breaking, the welfare of this country depended in no small measure upon ropes. All the minerals obtained from the bowels of the earth were lifted by ropes, and the risk of ropes breaking must always exist. It was idle to talk about not using ropes when it was a more economical

way of carrying on the traffic of a district like this. No definite principle could be laid down, but each question must be dealt with as necessity and as the means at disposal required.

Mr. G. Broadrick regarded the system of breaks introduced on this railway as a matter of great importance, seeing that the action was produced upon the rails instead of upon the wheels of the break-van. He considered that was the proper principle for the application of breaks, and it appeared capable of unlimited application. In these days of extreme inclines, a system of breaks through the medium of the rails instead of the wheels was a matter worthy of the consideration of engineers.

Mr. C. Neate remarked that of the three Brazilian railways which, like the São Paulo, ran inwards from the coast, viz., the Pernambuco, the Bahia, and the Dom Pedro Segundo, from Rio de Janeiro, the latter was the only one comparable with the São Paulo, because both had to climb the same mountain range, the Serra do Mar, which skirted the southern part of the Brazilian coast. In one case this ascent was accomplished by means of a locomotive line, in the other by inclines with stationary power. The Dom Pedro Segundo line was well laid out by American engineers. The Serra at this point was more accessible than at Santos; it did not present so steep an escarpment, nor so unbroken a line, but the works requisite for carrying a locomotive line over it were nevertheless of a most formidable character. The ascent on the Dom Pedro Segundo was only 1,350 feet against 2,600 feet by the Santos pass. It was 15½ miles in length, 10 miles of which consisted of gradients of 1 in 55, and the line doubled three times on itself in the course of the ascent, having frequent curves of from 800 feet to 900 feet radius. There were twelve tunnels in this distance, of the aggregate length of 15,000 feet, one alone being 7,000 feet in length. The ground was side-long for the most part, and the character of the cuttings upon it was very much the same as on the Santos inclines, having the same long slopes and requiring the same revetment walls and other works of protection. As regarded economy of first cost, therefore, the comparison was strongly in favour of the São Paulo line. On the Dom Pedro Segundo railway American bogie engines were used and worked very well.

Mr. V. G. Bell said, the comparative merit of stationary and locomotive power on various gradients was certainly too large a question for the limits of the present discussion. The Author of the Paper, in his anxiety to uphold the rope system, had greatly overstated the cost of working a locomotive line, and had entirely begged the question by confining himself to a gradient of 1 in 40. With respect to the use of locomotives on an incline of 1 in 10, as laid out, he would remark that if the ordinary adhesion of a locomotive were supplemented either by employing the centre

rail system, or by means of a rack rail, or any other method, by reducing the speed to 5 miles or 6 miles per hour, a tractive force could be obtained equal to $\frac{1}{3}$rd, or 747 lbs. per ton of the weight of the engine. Then, the gravity on a gradient of 1 in 10 being 224 lbs. per ton, and the other resistances about 25 lbs. per ton, to allow for the extra friction of the special system employed, a total tractive power equal to 249 lbs. per ton of the train was required. The gross weight of the train might thus be three times the weight of the engine; and to carry the traffic now passing over the incline, there would be a gross weight of trains of 900 tons per day in each direction. Without entering into any calculation, he would take the amount of coal consumed on the Mont Cenis railway, to lift this load of 900 tons to a height of 2,550 feet, which was 7 tons; though he must remark that the amount of power absorbed by friction on that line was enormous, on account of its sinuosities, it being a constant succession of curves of 2 chains' radius, and also on account of the complication of the engines. For the other items of the estimate he would take Mr. Fox's train mileage rates, although they were much in excess of ordinary rates; and he would double the locomotive charges, as the speed he was taking was one half. With an engine weighing 38 tons, eight trains per day in each direction would be required, which gave 80 train miles: to which, according to Mr. Fox, 20 per cent. should be added for standing, or a total of 96 train miles.

	£.	s.	d.
Coal, 7 tons, at £2 5s. =	15	15	0
Other running charges, 96 train miles, at 1s. 4d. =	6	8	0
Repairs of locomotives, 96 train miles, at 1s. 7½d. =	7	16	0
Repairs of carriages =	1	0	0
Watering station =	0	10	0
Maintenance of road and works, 5 miles, at 18s. =	4	10	0
Total expense per day . .	£35	19	0

as against £45, the expense at present.

The actual cost of doing this work on the Mont Cenis railway would be £44; although on account of defective materials and workmanship, and, to a certain extent, defective design in the engines, the proportion of this sum for repairs of rolling stock amounted to £16. He thought, therefore, that locomotive power was the cheapest mode of working railways, even with gradients as steep as this. For what were the causes tending to make the expense of working with locomotives greater than with stationary power? Clearly only the extra fuel required to lift the weight of the locomotives; in the case under consideration 33 per cent. of the fuel, or in money £5. 5s. On the other hand, what were the extra expenses entailed by the stationary system? An extra charge for salaries and wages of £7. 12s., and for repairs of engines, ropes,

pulleys, &c., of £2. 4*s*., making a total of £9. 16*s*. If, therefore, by more economical working, or by working the inclines to a greater extent in a self-acting manner, one half the amount of fuel at present used could be saved, locomotive power would even then be the cheapest.

Mr. J. Bayliss thought the objection to the use of rope-traction on the Serra incline, on the score of the possibility of accident from the fracture of the rope, might with just as good reason be extended to the use of railway locomotives, because an axle occasionally broke, and because there was a liability to accidents from the passage of locomotive trains. As a question of safety, he thought the rope traffic on this incline would bear favourable comparison with locomotive traffic; as in case of accident the train could be stopped within a distance of 50 yards or 60 yards, and that could not be said of any train hauled by locomotives.

He did not see anything to recommend the adoption of the atmospheric system for a railway in such a country as Brazil. In the first place, a double line of rails would have to be laid down to utilise the advantage of the down load assisting the up load. Then there was a want of skilled labour in Brazil, and this would be essential in carrying out a principle which, with every advantage, had proved unsuccessful in Europe; and the expensive paraphernalia, and the constant leakages inseparable from the application of the atmospheric system, would be far more objectionable and difficult of remedy in Brazil than in England.

Mr. Hemans had reduced some of the items set down for repairs of locomotives per mile and for maintenance, in estimating the cost of working the Serra as a locomotive line; but he thought in many cases the comparison was not fairly made; nor could he admit a difference of only £2 per day, as compared with working by the rope system. If the estimate for the rope system were treated in the same spirit, the £45 could be reduced almost in the same proportion as the £67 had been lessened. In a Paper "On Steep Gradients of Railways, and the Locomotive and Stationary Engines employed,"[1] by Mr. C. R. Drysdale, that gentleman, who had been engaged under Mr. Hemans, stated that "the total cost of working an incline on the Edinburgh and Glasgow railway for one year was £734. 18*s*. 1*d*. when the traffic was worked with a wire rope by a stationary engine, and £3,204. 16*s*. 10*d*. when locomotives were used, giving a difference of £2,460. 18*s*. 9*d*. in favour of the wire rope system." He attributed this great difference, to some extent, to the fact that the coal used for stationary engines in that district, was cheap as compared with coke; still,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 319.

the margin of difference was very wide. He agreed with Mr. Hawkshaw that the question of incline roads *versus* locomotive roads, must be left to the discretion of the Engineer, guided by the special circumstances which surrounded each particular work. In this case he considered the Engineer had no alternative but to make the line as he had done; and his opinion had been much strengthened by the estimate of Mr. Lane, the Government Engineer-in-Chief, than whom no one was more competent to express an opinion as to the value of works in the Empire of Brazil, who stated that a locomotive line up the Serra would cost, mile for mile, as much as the incline road; and this would be £2,000,000 for a locomotive road, as compared with £500,000, the cost of the incline road.

Strange as it might appear, in a country abounding with timber of the finest description, there was no alternative but the adoption either of iron sleepers or of creosoted timber for the permanent way. He concurred with the Author in his predilection for an iron road; and he could corroborate the statement as to the difficulties and annoyances experienced from the multiplicity of parts in the Greaves' system. The suggestion that all the sleepers should be cast of one pattern was valuable for such a country as Brazil. The Author proposed that every sleeper should be so cast as to admit of a tie-bar being used; but he would urge, not only that every sleeper should be so cast, but that the tie-bar should positively be used, as there was a tendency of the road to spread out on curves, especially when the curves were laid on deep embankments, subject to much settlement. The fact that the Contractor preferred to carry the cuttings to spoil, and to make the embankments from side cuttings, was due, he thought, to the difficulty of tipping earth for the embankments, which involved the employment of a great many horses, and there was considerable difficulty in obtaining proper 'tip' horses in Brazil. In his own case he had been driven to import horses from England, and subsequently to the use of bullocks, with a long length of chain between them and the wagons, for tipping purposes; but the latter expedient was attended with considerable danger.

He had not, like Mr. Fox, quitted those primeval forests with a blanched countenance for want of sunlight, but with one more like a Red Indian's: that, however, might be accounted for by the fact, that he was placed within 7° or 8° of the equator, while Mr. Fox was in a more temperate latitude. It was true that Englishmen in Brazil sometimes "lost their head;" but they more frequently lost their life. On the works upon which he was engaged 75 per cent. of the Europeans sent out were lost by death, by invaliding home, and taking into account a small number who absconded. He was himself present at the funerals of six of

his best men in the short space of ten days; and whatever might be the credit of constructing works in that distant country, it was mixed with a fearful alloy in the reflection of the loss of life that had been entailed in prosecuting them.

The cost of this line was stated to be £31,570 per mile; but of that amount about £7,530, or nearly 31 per cent., had been absorbed by the payment of interest on capital during construction. He alluded to this because friends of his had remarked that £31,000 per mile was a very heavy cost for a railway in a country like Brazil. The actual cost of the works, including rolling stock and administration, did not exceed £24,040 per mile.

The late Mr. Robert Stephenson had stated that throughout his experience he found that ordinary estimates for works of this kind were worse than useless, and never failed to mislead. That being the opinion of a man whose professional talents were universally acknowleged, it was matter of pride to the Engineers, and of congratulation to the Company, that works of such magnitude had practically been carried out within the estimates.

Mr. J. A. Longridge observed that the Engineer of this railway had to carry the line from a low level to a high one in a very short distance, and the only possible plan of doing so, he presumed, was by a steep gradient, and by adopting the rope system for working the traffic. He doubted whether, with the increased information of the present day, if Mr. Brunlees had to lay out the line again, it would be possible to develop it by means of curves so as to get a gradient of 1 in 15; but if it had been possible to do so, at nearly the same cost as the present gradient, he thought, from what Mr. Brunlees had seen since, he would probably not have adopted incline planes. The experience of the centre rail proved that an incline up to a certain gradient could be worked as cheaply, if not cheaper, by the locomotive, as by the rope. He had calculated that in rising to a height of 2,550 feet on the Mont Cenis line, with a gradient of 1 in 14½, which was the average gradient of the line from Susa to the frontier, it could be worked with a traffic of 580 tons a-day each way, at a cost of £40. 10*s.* per day, or taking the up load and the down load at 1½*d.* per ton per mile, while the expense of working these inclines was £45 per day. Now, from his experience of working rope inclines in olden times, he thought that in England where coal was cheap the cost could not be reduced much below that. Therefore, where a line could be developed with a gradient of 1 in 14 or 1 in 15, he was certain the locomotive system with the centre rail would be cheaper. He did not say that was the best plan that could be obtained; but it was the best yet known. The Mont Cenis line had always been worked under great disadvantages, and the experience gained there was certainly on the safe side. A locomotive line had this advantage over the

rope or the atmospheric systems—that the amount of traffic which could be carried was unlimited, whereas on every other system it was limited.

Mr. J. Coode said he had been requested to call attention to the fact, that a clip break, on the same principle as that adopted on the São Paulo incline, had been in use for the last seven years on an incline leading into the celebrated Botallack copper mine in Cornwall, which was remarkable from the fact that it was worked to a considerable extent under the bed of the sea. Leading down to that mine there was an incline of 1 in $1\frac{1}{2}$ for about 1,100 yards in length. A serious accident happened there eight or nine years since, by which several men were killed, and subsequent to that the clip break was introduced, and had been worked with success. It was to a certain extent self-acting; the tail of the rope was attached to a draw bar: a spring was introduced, and if the rope broke the spring immediately caused the clips to come into action with a limited amount of pressure on the sides of the rail, which could be increased by the man in charge of the train, through the intervention of a lever which he kept in his hand. The rope had broken on two occasions, and the wagons were brought up immediately without difficulty and without accident. The inventor of this break was Capt. John Rowe, of the Botallack mine.

He would now refer to the durability of the rope in use on the Serra inclines. He had no experience to warrant him in saying one word as to the comparative merits of rope and of locomotive propulsion, but having worked an amount of traffic with wire rope, which represented the traffic that would travel over this incline, at the present rate, for a hundred years, he might be considered competent to speak on the subject of working with rope traction. He was struck with the statement in the Paper that the duration of the life of the rope on this incline was only about two years. As the traffic comprised 77,000 tons per annum of paying load, that represented a gross weight of about 146,000 tons per annum, or in round numbers say 150,000 tons. That multiplied by 2, being the duration of the rope in years, gave 300,000 tons as the gross work of the rope. The ropes he had worked had been employed on inclines of 1 in 10, as in this case, but of only about one-fourth the length, with some slight curves at the bottom of the landing. The duration of the ropes there was about eight years, during which time the work done was represented by 8,000,000 tons of gross work for a distance about one-fourth of that of the Serra inclines: reducing it to that distance it would make the duration of the rope 2,000,000 tons, but the trains in this case averaged 50 tons weight each as compared with 40 tons in the case of the Serra: thus there were obtained 1,600,000 tons' work out of the rope in the former case, as compared with 300,000 tons'

work on the Serra. It appeared, after making every allowance necessary to institute a fair comparison, that about five times more work was done by the iron-wire rope than by the steel-wire rope on the Serra inclines. The São Paulo rope was of steel, 4 inches in circumference, and was composed of No. 10 Birmingham wire gauge; that which he used was of iron, $4\frac{7}{8}$ inches in circumference, and was composed of No. 8 Birmingham wire gauge. He thought there was room for improvement somewhere, or else—what he should be astonished to find was the case—the steel-wire rope was less durable than the iron-wire rope. The iron-wire ropes were subject to two kinds of destructive agency,—one from within and the other from without. They had a core of hemp: in fact, ropes for such purposes were six-stranded, each strand being composed of six wires, with a hempen core in the middle of each strand, and a large core in the middle of the rope. When he commenced the use of these ropes, he made inquiries with respect to the behaviour of the ropes on the Blackwall railway; and he was informed that they could not be kept in order, unless means were adopted for preventing oxidation. He was also told that the notion obtained, that there was an acid in the hemp which acted chemically upon the rope. He had never been satisfied on that point, and thought that simple oxidation alone had to be guarded against. The hempen cores would no doubt absorb moisture to a considerable extent if not guarded against, and precautions should be taken to prevent that absorption, which might be done, and the rope kept soft and pliable, by 'paying' it over with a mixture of raw linseed-oil and Stockholm tar, in the proportion of 1 quart of oil to 1 gallon of tar. With regard to the destructive action from without,—a slight touch on the break, or a little inequality in the road, caused the rope to jump and surge upon the rollers, and that gave rise to a considerable amount of wear and tear on the external surface. That was prevented, to a certain extent, by what was called 'serving' the end of the rope with fine charcoal-made iron wire; but it cut out very frequently, showing that the rope would soon be destroyed but for this precaution. He was disposed to think that the ropes on the Serra incline might have suffered from the comparatively small diameter of the drums. In the case of a steel-wire rope of 4 inches in diameter, or of an iron-wire rope of $4\frac{7}{8}$ inches in diameter, he should not like to use a drum of less than 12 feet in diameter: for the rope was subjected to a constant operation of bending and straightening, on passing on to and off from the drum: that had, in his opinion, much to do with what he considered to be the comparatively small amount of traffic which these ropes had been able to convey. He had found it advantageous in his own case when the rope became worn to a considerable extent, to turn it occasionally end for end. The

importance of that would be seen—assuming the train to be at the bottom—by comparing a portion of the rope on any one of these inclines, say 20 yards from the drum, with a portion of the rope at the bottom. Calling the first part *a*, and the second part *b*, *a* would have travelled only 20 yards while *b* would have travelled 2,000 yards, and the wear and tear would be in the proportion of 20 to 2,000; so that it would be advantageous at a certain stage to turn the rope, as by that means it might be made to last twice as long as it otherwise would.

After using these iron wire ropes for three months, he would not have given them twelve months longer life, as the apparent amount of wear and tear was rather alarming. It was not that the rope had worn away, but it was found, on the removal of the tar and oil from the interstices, that the wire had been flattened out, so that there was a far greater amount of bearing surface than originally, and there resulted an amount of surface nearly equivalent to that of a continuous bar of iron with the flexibility of the rope. With that change in the form of the surface the ropes lasted eight years, and carried 8,000,000 tons of load, which proved that the amount of wear and tear under proper care and precautions was very small indeed. Whether the steel wire, from being comparatively unyielding, cut away, he could not say, but it was a point worthy of consideration. In the observations he had made he desired it to be understood, that he had not spoken in any way in disparagement of the system that had been adopted on these inclines, but simply from a wish to impart such practical information as he was in possession of.

Mr. J. N. Douglass, being intimately acquainted with the self-acting gripping break used at the Botallack mine, and having seen it tested under various circumstances, desired to bear his testimony to its entire efficiency for the purposes to which it was adopted. He thought it should be placed upon record that the invention of this ingenious contrivance was due to Captain John Rowe, the Engineer of the mine. It had been in successful action on the Botallack incline for the last seven years.

Mr. Brunlees, in responding to several points raised in the discussion, observed that the objections taken by Mr. Hemans had been so fully answered by Mr. Hawkshaw and Mr. Bayliss that he need not further refer to them. It was suggested by Mr. Heppel that the inclines should have been steeper and shorter, the facial angle of the Serra being 1 in 4. No doubt in that way a cheaper line could have been constructed, which would have answered well had the traffic consisted of goods or mineral only; but as passengers had also to be carried, he considered he was justified in providing the best gradients that could be obtained with the capital at his disposal. It was stated by Mr. Lloyd that the

inclines were dangerous because ropes were apt to break. The best reply to that remark was the fact, that during five years there had been but one breakage of a rope, and in that case the train was so quickly pulled up by the clip break, that there was neither accident nor danger. Mr. Bramwell, in objecting to the engines being worked at so low a pressure, had overlooked the fact that they were designed for a large prospective traffic. Dr. Pole had suggested the applicability of the atmospheric system for inclines steeper than could be worked by locomotives. This had been well considered by Mr. Brunlees before arriving at the conclusion to use ropes. His reasons were that the atmospheric system would require tubes of 40 inches in diameter, would be very costly to begin with, more costly to work than the rope system, and the time required to exhaust the tubes for each trip would be lost, and consequently less traffic could be conveyed in the same time. Moreover, with such large earthworks and such heavy rainfalls, it would hardly be possible to maintain tubes in working order, and he felt doubtful as to the effect of the great alternations of temperature, especially on the top lifts of the Serra. Mr. Coode referred to a clip break which had been in use for seven years, constructed on a somewhat similar principle to that used on the Serra. It did not appear whether Mr. Coode wished to claim priority for the break referred to, but Mr. Brunlees could state that the Serra break was designed in 1860, on his return voyage from Brazil. Mr. Coode also referred to the greater life of ropes he had employed than that assigned to those used on the Serra inclines. No doubt the system of forming the figure 8 between the two pulleys at the engine-house, in order to obtain friction, was injurious to the ropes; and to obviate this destructive tendency he had recommended the use of Messrs. Fowler's drums, which would give all the friction, without any reverse bending of the rope in passing round the drum.

March 15 and 22, 1870.

CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

The discussion upon the Paper, No. 1,245, on "The São Paulo Railway," by Mr. D. M. Fox, was continued and concluded.

At the latter meeting a Paper on "Rotary Fans," by Mr. Robert Briggs, was read; but as the discussion upon it was postponed, the Paper and the report of the discussion will be printed together, later in the present volume.

March 29, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

No. 1,253.—"Description of the St. Pancras Station and Roof, Midland Railway."[1] By WILLIAM HENRY BARLOW, F.R.S., M. Inst. C.E.

THE system of lines known as the Midland railway commenced by the amalgamation of the Midland Counties, the North Midland and Birmingham, and Derby railways, each of which was at the time of their amalgamation in a very low financial condition. The aggregate length of the Midland railway was at this time (1844) about 200 miles. The advantage of the unity of action of these three railways was very great, both to the shareholders and to the public, and manifested itself rapidly. In a short time the Birmingham and Gloucester, the Sheffield and Rotherham, the Leeds and Bradford, and the Leicester and Swannington were added to the system, by lease or amalgamation, while the united Company constructed new lines to Lincoln, Peterborough and Burton, the Erewash Valley, and the Nottingham and Mansfield, besides other smaller lines. Shortly afterwards terms were made with a line which united the Leeds and Bradford with Lancaster and Morecambe Bay. The traffic arising from the connection of these large manufacturing towns, and that from the rich coal districts of Derbyshire and Leicestershire, was at this time dependent for its access to London solely on the London and North Western railway. In 1857 the Midland opened the Leicester and Hitchin railway, whereby they acquired a second line of communication to London by the Great Northern. At a later period the Midland Company constructed a line from Rowsley to Buxton, in Derbyshire, and previous to opening this acquired powers to construct a branch from the Buxton line to the Sheffield and Lincolnshire railway at New Mills, thus obtaining a direct means of communication with Manchester and the surrounding districts in Lancashire.

The Midland railway having thus generally altered its character from a local line to that of a great system possessing access to numerous large and important towns, to the commercial centres of Yorkshire and of Lancashire, and to the rich mineral districts of

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

Derbyshire and Leicestershire, it was determined at last to apply to Parliament for power to make a line to London.

Starting from Bedford, the line runs through St. Albans and Luton, and enters London by a tunnel under Haverstock Hill, and finally has its terminus close to the Euston Road, in the parish of St. Pancras, in the immediate vicinity of the King's Cross Station of the Great Northern railway.

Some distance from the terminus, a branch of two lines of rails leaves the main line, gradually descends through a tunnel beneath the new passenger station, and joins the Metropolitan railway near their King's Cross Station.

The Midland Company had previously formed a goods yard of their own in London, which communicated with the Great Northern railway main line during the time of their working arrangements with that Company. An increasing goods traffic, and the consequent necessity of further goods accommodation in sidings, sheds, warehouses, &c., pointed out the advisability of acquiring as much land as possible in the vicinity of their goods station in London, and accordingly, when the Company were offered an estate adjoining the Euston Road on advantageous terms, they lost no time in making the purchase. The tenure of this estate determined the site of the new station. The approach to this station land was crossed by the Regent's Canal, at a distance of about 45 chains north of the Euston Road; and in order to secure good gradients and suitable levels for stations at Camden Road, Kentish Town, and Haverstock Hill, the main passenger line was carried over the canal. It resulted from this arrangement that the level of the St. Pancras Station was from 12 feet to 17 feet higher than that of the adjoining roads.

The St. Pancras branch, on the other hand, for effecting a junction with the Metropolitan railway, was taken at a lower level crossing under the Regent's canal, as well as under a considerable length of the main line and its works, including the passenger station.

In consequence of the height of the rails above the ground level, a large space extending over the whole area beneath the station, was available. The original design was to fill this space with the material excavated from the tunnel of the St. Pancras branch, and it was contemplated to make the roof of the passenger station either in two or in three spans. But the station being bounded on the south by the Euston Road, on the east by the old St. Pancras Road, and on the west by Brewer Street, and the difference of level being such as to admit of the construction of a lower floor with direct access to these streets, the position was deemed so valuable that it was determined by the directors to devote the whole area to traffic purposes, communication being made with the rails by means of hydraulic lifts. The special purpose for which this lower floor has been arranged is for Burton beer traffic; and in order

to economise the space to the utmost, it was determined to use columns and girders, instead of brick piers and arches, making the distances between the columns the same as those of the warehouses, which were expressly arranged for the beer traffic. Thus, in point of fact, the length of a beer barrel became the unit of measure, upon which all the arrangements of this floor were based.

This decision led to a reconsideration of the question of roofing the station. It became obvious that, if intermediate columns were employed, they must be carried down through the lower floor, be about 60 feet in length, and of much larger diameter than the rest of the columns under the station. This would have necessitated the employment of different patterns in the girders, cross girders, and in the plating of the lower floor, and have increased the price per ton for that portion of the ironwork, besides interfering with the economical distribution of the space. Moreover, these columns must have carried large areas of roofing in addition to the flooring, involving a greatly increased weight on the foundations, which must have been enlarged accordingly; and as some of them would necessarily have been placed on the tunnel of the St. Pancras branch, special means and increased expense would have been required to carry the imposed weight at those places.

On the other hand, it was seen that the floor girders across the station formed a ready-made tie sufficient for an arched roof crossing the station in one span; all that was required to obtain a roof of this construction being the arch or upper member of the truss, of which the floor girders would form the lower member. There was a third feature in the case. In iron roofs as usually constructed, the depth of the principal is about one-fifth of the span; but here, by adopting one arch extending across the station, the height from the tie beneath the rails to the crown of the arch became the effective depth of the truss; and this height being about two-fifths of the span, all the horizontal strains arising from the dead weight of the roof, its covering, and accumulations of snow, &c., would be about the same in the arch of 240 feet span, with an effective depth of truss of 100 feet, as in an ordinary truss of 120 feet span with a depth of 24 feet. Excepting, therefore, such additions as might be necessary for retaining the form and figure of the arch, the actual sectional area at the crown, and for about two-thirds of the entire arch, did not require to be greater than in an ordinary truss of 120 feet span. There were several other advantages belonging to the arch,—one being that as the weight of the roof was carried at the floor line, and did not rest on the tops of the walls, there was no necessity to make the side walls thicker, for not only was the weight on the tops of the walls avoided, but also the racking motion from the expansion and contraction of an ordinary roof, which, though

it may be mitigated, is not prevented by the use of roller-frames at the feet of the principals, and appliances of a like nature. It was also apparent, that the arch might be made of rivetted plate ironwork like that of an ordinary railway bridge, and that the expense attending the use of forged and wrought work as in ordinary roofs would be avoided, including the screw-cutting, gibs and cotters, welding, and similar costly workmanship. Again, as to the question of the expansion and contraction of the arched roof, the ties being beneath the ballast, the temperature would vary so little, that no provision would be necessary; and for the arched part of the roof, which would alone be subject to appreciable change, the only effect would be a slight rise or fall in the crown.

All the arrangements of roller-frames or slings, required in ordinary roofs to provide for the effect of variations of temperature, would, therefore, be avoided by the adoption of the arch; and lastly, the adoption of a single arch would not only save the cost of the columns and their foundations, but also that of the longitudinal girder required to connect them at their upper extremities, with a valley drain between the roofs, and vertical drain pipes, and other provisions for taking off the water from the area, between the centre lines of the two roofs, which would have been about two acres.

All these circumstances tending to favour the idea of one arch across the station, the remaining question was, what depth and form of rib, and what additional material, must be employed to make an arch sufficient to retain its form under all conditions of stress arising from its own weight, from snow, and from heavy gales of wind. The results arrived at on this subject, partly by calculation and partly by experiment, were—

1st. That the depth of the rib must be sufficient to contain all the lines of pressure generated by the dead load, by snow, and by the pressure of the wind;

2nd. That the sectional area of the metal should be sufficient to sustain the whole stress without producing a strain on the iron exceeding 3½ tons per square inch.

3rd. That the arch should be rivetted together with proper joint-plates throughout, so as to give it the advantages of complete continuity.

The probable additional cost of principals so constructed, of 240 feet span, as compared with principals of two spans of 120 feet and their columns, was estimated at about £6,000. Notwithstanding this, the importance attached by the Directors and the General Manager to obtaining perfect freedom in the use of the whole area of the station for traffic purposes, unembarrassed by columns or other impediments, was such, that instructions were given for an arch in one clear span.

The main features of the work being thus determined, the plans

and arrangements of the station were immediately proceeded with. The brickwork of the substructure of the station, including the St. Pancras branch which passed beneath it, and the whole of the works of the upper and lower lines of railway, extending for a distance of ¾ of a mile northwards, formed one contract involving many complicated works. This contract was let to and carried out satisfactorily by Messrs. Waring, under the superintendence of the Author's principal assistant, Mr. Campion; while the iron-work of the several bridges, viaducts, and other structures, including the columns and girders of the lower floor of the station, was in charge of his assistant, Mr. Grier. For the details of the roof the Author is indebted to Mr. Ordish, whose practical knowledge and excellent suggestions enabled him, while adhering to the form, depth and general design, to effect many improvements in its construction.

While these matters were proceeding, competitive designs had been invited from several of the most eminent architects for the station buildings, booking-offices, and hotel, the architects being furnished with the plans of the several buildings, showing the position of the booking-offices, waiting-rooms, and hotel, and with the design of the station roof to which the interior walls were to be adapted. In the end the design of Mr. Gilbert Scott, R.A., was adopted, and the services of that eminent architect were secured to carry out the station-buildings and hotel above the level of the foundations.

The general arrangement of the station follows the type suggested by the stations at Cannon Street, Charing Cross, and Victoria, in so far as the arrival trains are brought in on both sides of a carriage-road in the interior; but it differs from them in this respect, that the main booking-offices are on the side instead of at the end of the platforms. There are, however, other booking-offices at the end, which may, if necessary, be used for a central platform.

The arrangement of the platforms and rails of the passenger station is shown on Plate 8. There is nothing calling for special remark except that there are three tiers or levels of rails, the lowest being the St. Pancras branch, which crosses on a curve obliquely from the western to the eastern side. Above this are the rails of the lower floor, and above this again are the rails and platforms of the passenger station. The Midland Company also constructed a portion of the second line of the Metropolitan Railway, which passes under the end of the hotel and under the southern road-approaches of the station.

Extensive arrangements have been made outside the station for the delivery of coal in the St. Pancras Road; also in Cambridge Street and in the canal basin constructed for the interchange of traffic between the railway and canal. All these places have been fitted up with the most recent and approved apparatus for unloading

coals, and other similar works are in course of construction in Brewer Street. The frontage of the lower floor of the station abutting on the adjoining roads, where not required for the purposes of the railway, has been fitted up for shops, the space so used being that comprised between the walls of the station and the roads.

The area of the passenger station roofed in appears large from the circumstance that there are no columns or other impediments to obstruct the view; but as a matter of fact it is not so large as some of the other terminal stations in London.

The following statement shows the relative roofed area of some of the principal termini:

Name of Railway.	Name of Station.	Area measured within the Walls in Square Yards.	Length of the Railway System accommodated.
London and North Western	Euston Station . .	23,144	
Great Northern	King's Cross Station	22,808	
Midland	St. Pancras Station .	18,822	
South Eastern	Cannon Street . . and	13,875	
,, ,, ...	Charing Cross Station	8,888	
Great Western	Paddington Station.	28,807	
	Victoria Station, about	40,000	

Description of the Lower Floor (Plate 9).

The lower floor contains seven hundred and twenty cast-iron columns set with stone bases on brick piers. There are forty-nine rows of principal girders across the station, and fifteen similar girders running longitudinally. These carry intermediate girders, and the whole is covered with Mallet's buckle-plates. The strength of the girders and plating is sufficient to carry locomotives all over the floor, of which the cost of the ironwork was £57,000, or nearly £3 0*s.* 6*d.* per square yard.

Description of the Roof.

The main ribs or principals are made of channel-iron and plate-iron, and are 6 feet deep, or one-fortieth of the clear span. The rib between the walls is of open work, but the extremities of the principals in the walls are of solid plates.

	Tons.	cwt.
The weight of the feet or pedestals is 9 tons 18 cwt. × 2 =	19	16
And of the open-work, extending from wall to wall	35	0
Thus the total weight of each rib is	54	16

The cost of each rib is as follows:—

	£.	s.	d.
Wrought ironwork in rib, 54 tons 16 cwt., at £18. 10s.	1,013	16	0
Four holding-down bolts	49	0	0
Four anchorage castings	24	12	0
Two moulded bases	12	8	0
Two ornamental spandril frames	32	8	0
	£1,132	4	0

The ribs project in front of the piers of the walls, and the piers project from the line of the wall. The width, measured between the walls, is 245 feet 6 inches, and the distance from centre to centre of the ribs is 29 feet 4 inches. The arch is slightly pointed at the crown, as this form apparently possesses some advantages in resisting the lateral action of wind, while it improves the architectural effect. The radius of curvature was diminished at the haunches, to give increased head room near the walls. The mode of making the joints and fastenings is fully shown on Plate 8. The glazing is ridge and furrow, ventilation being obtained along the whole length of each ridge, which is left open and protected from wet by a ventilator cover: the ventilation is thus very complete. The roof is also provided with gangways throughout, so that any pane of glass can be taken out and replaced. The gable ends or screens consist of three horizontal lattice girders, 6 feet wide, united and carried by verticals of similar construction. Their arrangement and the mode in which they are connected with the principals or main ribs of the roof will be readily seen on Plates 8 and 9.

The erection of the roof was effected by two large timber stages, each made in three divisions, so that each part of either stage could be moved separately. These stages were designed by the Butterley Company, who were the contractors for the roofing and for the lower floor, Mr. (now Sir) G. J. N. Alleyne being the manager. The stages were 40 feet in width, of great strength and solidity, and contained about 25,000 cubic feet of timber and 80 tons of ironwork. The weight of each stage was about 580 tons, and with two ribs on it, the weight on the floor-girders where it stood, including men and apparatus, was about 650 tons. The passage of these two stages, which moved on wheels, along the floor of the building, constituted a good test of the strength of that portion of the work.

The process of erecting was as follows; the two lower portions or the feet of the ribs were first set temporarily in position, the brickwork underneath them being kept about 3 feet below its intended height. The feet were then accurately adjusted by timber-packing and wedges, and rivetted to the ends of the floor-girders; after which the brickwork was carried up in blue Staffordshire bricks set in Portland cement, and the whole secured to the under-

side of the ironwork, the timber-packings being removed as the brickwork proceeded.

The open work of the main ribs was commenced from the extremities on each side, in divisions of about 18 feet in length, and these were placed temporarily together, supported by the staging, until all the pieces were in position. The whole was then adjusted for line and level, and rivetted together with the purlins and other ironwork.

The time required for putting up the pieces and rivetting, after the feet were fixed, was six days for each rib, and the last fourteen principals were erected in seventeen weeks, including delays from weather, and occasionally failure in the supply of materials and other causes. The ironwork was lifted by an ingeniously contrived engine, which worked ropes to derricks placed on the stages. The supports were adjustable on the stage. Special arrangements were employed to secure the line, form, and level of the work; and, the whole of the ironwork having been fitted at the Butterley Works, it was put together without difficulty. The greatest depression of any rib when the centre was struck was only $\frac{1}{4}$ of an inch, and the average was $\frac{3}{16}$ of an inch.

The contract provided for testing the roof; but the extreme stiffness of the work, and the unavoidable tests to which it was from time to time subjected during erection, were sufficient to show that no formal testing was necessary. In consequence of a delay in obtaining face-bricks for the side walls, a considerable number of ribs were erected, boarded, slated, and glazed before the side walls were built, and in that state the roof endured several gales of wind, one of which was unusually heavy, without the slightest visible movement. The lines of the roof are remarkably well preserved.

The Butterley Company are entitled to great credit for the manner in which the roof has been constructed, and their managing foreman on the works, Mr. Clark, is deserving of special mention, for erecting the work and putting it together on the ground.

Strength of the Roof.

In arranging for the strength of a roof of this form, there were no precedents of sufficient magnitude to be available. In the three roofs of large span previously erected—namely, those of the stations at New Street, Birmingham, and at Cannon Street, and Charing Cross, London, trusses were used of an arched form, having a tie-bar and connections at intervals between the tie and the upper member of the truss, which serve to keep the arch in form. At St. Pancras it was required to construct an arch capable of maintaining its own form, without any intermediate connections with the tie. Under

Name of Station.	Span of Roof Truss.	Depth measured from top of Arch to Tie.	Surface of Roof carried measured on Plan.	Description of Covering.	Estimated Weight of Covering per Foot super.	Weight of Principal or Truss.	Sectional Area under Maximum Compression.	Sectional Area of Tie-bar at Centre.	Remarks.
	Feet.	Feet.	Sq. Feet.		lbs.	Tons.	Sq. In.	Sq. In.	
New Street Station. Birmingham	211	23	5,064	Corrugated iron and glass.	20	25	35·05	12·56	The principal is carried at one end by a wall, and at the other by a column weighing 5 tons 10 cwt.
Charing Cross Station . .	166	30	5,810	Boarded and slated and glass.	37	27	27·00	14·18	Carried by walls.
Cannon Street Station . .	190	30	6,460	ditto	37	37*	33·76	22·14	Ditto ditto.
Lime Street Station, Liverpool	212	22 9	6,784	ditto	38	44	50·37	33·00	Carried by two columns, each weighing 5 tons 10 cwt.
St. Pancras Station . .	240	107	7,040	ditto	36	54	46·00	..	Springs from ground level. Weight of pedestals included in truss.

* There are also about 5 tons 10 cwt. of cast-iron work in bed-plates, bearing-plates, waiters, and castings, for the ends of the ribs.

these circumstances it was considered expedient to adopt a low rate of pressure upon the metal, with a large assumed weight acting in addition to the weight of the principal. With this view, and to remove all doubt on the question of strength, the arch was designed so as to be capable of bearing an assumed load of 70 lbs. per square foot measured on plan, in addition to the weight of the principals, with a stress on the metal not exceeding $3\frac{1}{2}$ tons per square inch; or, what amounted to about the same thing, a load of 56 lbs. per square foot, with a stress of 3 tons per square inch. Of the 54 tons 16 cwt., the weight of the rib, a portion belongs to the connecting medium with the ties; excluding this portion, the weight of the rib is as follows:—

	Tons.
The open-arched part between the springings	35
The feet or pedestals, 9 tons 10 cwt. each . . . . . =	19
	54

The surface carried by the arched portion of the rib is 240 feet × 29 feet 4 in. . . . . = 7,040 square feet

	Tons.
And with the assumed weight of 70 lbs. per foot, the assumed load is 7,040 × 70 lbs. . . . . =	220
Add weight of arch . . . . . =	35
	255

The line of pressure forms an angle of 55° with the horizontal at the springing, and therefore the pressures are—

	Tons.
At the springing	155
And at the crown	89

The sectional area of the rib is 46 square inches; viz., 23 square inches in the upper flange, and 23 square inches in the lower flange; so that the stress on the metal with the assumed weight of 70 lbs. per square foot, is—

	Tons.	
At the springing	3·37	per square inch.
And at the crown	1·94	,,

Experience has proved that in large roof trusses of the ordinary form, the strains generated by an assumed load of 56 lbs. per foot, in addition to the weight of the principal, may be from 4 tons to 5 tons in compression, and from 7 tons to 8 tons in tension, without exceeding the limits of safety. The reason for adopting so low a pressure at St. Pancras was that, in an arch of this form, and especially under the lateral action of wind, the line of pressure deviates more or less from the centre of gravity of the section. The effect of such deviation is to throw more pressure on one member of the rib than on the other; but the amount of the

difference so arising is controlled and modified by the depth and stiffness of the rib in resisting flexure, and also by the extent to which the channel-iron cross-bracing causes the pressures acting on one member of the rib to be transmitted to the other.

The experience derived from what may be termed involuntary tests during the erection of the ribs, and the great stiffness and almost total absence of deflection or disturbance of any kind which the roof exhibits, point to the conclusion that the strength of the structure is in excess of what was needed.

To enable those who take an interest in the subject to make a comparison, a statement is given in a tabular form of the principal dimensions and structural values of the five largest roof trusses erected (page 86). It includes the roof, now in process of erection by Mr. William Baker, for the London and North Western Railway, at the Lime Street Station, Liverpool, where the spans vary, the greatest being 220 feet. The truss of which Mr. Baker has furnished the Author with particulars is 212 feet span.

Cost of the Roof.

The roof as designed had twenty-four main ribs, and one gable or screen at the northern end. The southern end was intended to terminate against the walls, in the same way as the roofs of the Cannon Street and the Charing Cross Stations. But the acceptance of Mr. Gilbert Scott's design for the station offices and hotel led to this arrangement being departed from. In the original design the hotel was carried over the upper portion of the southern range of station offices; but as it was feared the steam and smoke of the engines would find entrance into the hotel windows, Mr. Scott planned a second gable and screen for the southern end, so as to separate the passenger station from the hotel buildings. This second screen involved an additional main rib, and to this extent the Author's original design has been departed from.

The cost of the roof as it stands in the finally settled accounts is as follows:—

	£.
For the twenty-four main ribs with foundation bolts, eastings for ditto, ornamental spandrils, and moulded basis, &c. . .	27,187
For the covering, including plate-glass, lead-work, purlins, intermediate ribs, wind-ties, gutters, ventilators, gangway, &c. .	26,296
Total cost of roof, excluding screens	£53,483
For the north gable	7,375
For the additional main rib, spandrils, &c., at the south end .	1,132
For the southern gable	7,375
	£8,507

The area within the walls, measured on plan, being 169,400 feet superficial, the following is the cost per square of 100 feet superficial:—

	£.	s.
For the twenty-four principals, or main ribs	16	1
For the covering, including purlins, &c.	15	10
Total cost of roof, excluding screens.	31	11
The additional cost per square of the north screen	4	7
The additional cost per square of the extra rib and south screen	5	0

The cost, compared with that of some other large roofs, is as follows:—

——	Span in Feet.	Cost per Square, exclusive of Gables.	Additional, for one Gable.
		£. s. d.	£. s.
Cannon Street	190	43 10 0	6 0
Charing Cross	166	34 0 0	6 0
St. Pancras[1]	240	31 11 0	4 7
New Lime Street Station	212	30 0 0	estimated cost.
Victoria Station, Great Western side .	120	27 13 4	with gable.

This is, however, no criterion of the structural values. The cost of such works is subject to variation by the price of labour and materials at the time of execution, by the locality of the work, and by the degree of rapidity with which it is pressed to completion; and it is subject to further and often larger variation by the financial condition of the company for whom it is undertaken. The contract price of the ironwork of the Cannon Street and the Charing Cross roofs was £24. 5s. per ton, as compared with £17. 10s. per ton for the new station in Liverpool; the structures in both cases being similar, and the description of work identical.

It has frequently been observed that there would have been a large saving, if the station roof at St. Pancras had been made in two spans instead of in one. Under ordinary circumstances this might have amounted to about one-third of the cost of the principals, but the additional expense attending the employment of columns in that case, in consequence of the lower floor and the tunnel beneath, would have lessened that difference considerably. As a mere question of space, it would have been questionable economy to adopt this course, for, as will be seen from the plan, the columns must have been placed where the station is

[1] The cost of the floor-girders, which perform the double duty of girders and of roof-ties, is taken as part of the cost of the floor. If there had been no floor-girders, the quantity of metal required for ties at that level would have made an addition of about £1 per square to the cost of the roof.—W. H. B.

laid out for rails; and their diameter, with the necessary clearance on each side, would either have caused the sacrifice of a line of rails, or have taken an equivalent width from the platforms.

When, therefore, it is considered that the Company obtained their station in the metropolis at such great cost for land and works; that its total area, in reference to the extent of railway, is less than that of any of the other important metropolitan termini, and that the Midland system is not yet in communication with all its expected sources of traffic, the sacrifice of a width of 5 feet or 6 feet, for the entire length of the most valuable part of the working space of the station, could hardly have been justified even if the saving had been greater than is estimated. As the station has been built, the whole working area is free from obstruction of any kind, and the Company may make any alterations in the arrangements of the lines and platforms which may from time to time best suit their large and growing traffic. The roof is of great strength; it is not more costly than other roofs previously erected, and in regard to its general effect and appearance, it will, probably, not be deemed unsuitable for the London terminus of so great and important a system of railways as that of the Midland Company.

The general question of the cost of roofing, considered purely from a structural point of view, and irrespective of those circumstances which affect the rise and fall in the prices of materials, is a simple problem.

The great governing element is the description of covering, as it affects both the cost and the weight. Light corrugated iron is not only cheaper than boarding and slating, but it is not much more than half the weight, and therefore requires less strength in the principals or trusses. The employment of iron sash bars, instead of wood, adds much to the expense of roofs: the former have the advantage of durability, but wood offers the best facilities for making watertight joints, and when prepared by Burnettizing or Kyanizing, is, perhaps, the most suitable material.

The weight and description of covering being decided upon, the strength required in the purlins will depend on their depth, and on the distance apart of the principals. In the St. Pancras roof the purlins are lighter than usual, because their depth is 5 feet 6 inches where they connect with the principals, and consequently the requisite strength is obtained with a small expenditure in material.

The trusses, or main principals, follow the same laws as all other weight-bearing structures. With the same description of covering and the same weight of purlins, the weight of material in the trusses varies nearly as the squares of the spans; accordingly, if estimated at per square of roofing, it varies directly as the spans.

With the ordinary truss, the distances between the principals being about 30 feet, and the covering being of boarding, slating and glass, the weight of metal required in the principals can be expressed approximately in tons per square of roofing by dividing the span in feet by 320.

Thus the following numbers give approximately the weights required for different spans:—

Span in Feet.	Weight per Square of Principals, in Tons.
80	·250
120	·375
160	·500
200	·625
240	·750

If the whole duty of the principals consisted in supporting the covering, the weights of the principals would be subject to variation in the direct ratio of the weight of covering; but a surplus of strength is always necessary to provide for the effects of wind and snow, and this surplus is a constant quantity, so that a reduction of one half in the weight of the covering does not reduce the weight of the principals more than about one-third.

These rules, however, though fairly borne out in practice, are not sufficiently accurate for very large spans.

In that case, and also for the comparison of the structural values of one class of truss with another, it is best to have recourse to the limiting span; that is to say, supposing a given structure, which is capable of carrying a given load with a given strain upon the metal, to be enlarged equally in all its dimensions, then, inasmuch as the sectional area of the metal on which the strength depends increases as the square of the span, while the weight of the structure increases as the cube, it follows that there is a span at which the weight of the structure alone, without any load, will generate the given strain on the metal.

Let w = the weight in tons of a given structure,
s = the span,
o = the load it can carry with a given stress on the metal,
L = the limiting span;

then $\frac{(o+w)}{w}\, s = \mathrm{L}$ the limiting span; and, provided that the stress on the metal is the greatest which can safely be used, the limiting span so arrived at becomes a modulus or measure of the structural value.

The following are approximately the limiting spans of some of the more commonly used weight-bearing structures:—

	Compressive Stress.	Tensile Stress.	Approximate Limiting Spans.
	Tons.	Tons.	Feet.
For a plated girder, depth $\frac{1}{6}$th of span .	4	5	500
Lattice girder, depth $\frac{1}{8}$th of span . .	4	5	536
Lattice girder, depth $\frac{1}{10}$th of span . .	4	5	672
Lattice girder, depth $\frac{1}{10}$th of span . .	4	5	768
Lattice girder continuous, Boyne Bridge pattern	?	?	888
Ordinary arched-roof trusses	$4\frac{1}{2}$ to 5	7 to 8	1000 to 1050
Pancras arched truss	2·8	..	1022
Ditto ditto	3·0	..	1086
Ditto ditto	3·5	..	1270
Suspension Bridge chain, versed sine $\frac{1}{10}$th of span	..	5	2220
Suspension Bridge wire rope	..	5	2400
Ditto ditto ditto	..	6	2880

The idea of treating the relative values of structures by means of their limiting spans is due to Professor Rankine. It affords a ready method of obtaining approximately the weight of an intended structure; for, when the limiting span of the class of structure is known, $\frac{o\ s}{\mathrm{L} - s} = w$.

Suppose it were required to ascertain the weight of the truss in the Liverpool roof, with a compression strain of 5 tons, and a tension of $7\frac{1}{2}$ tons:

Here the load to be carried, estimated at 56 lbs. per foot on 6784 feet of roofing, equals 170 tons; the span is 212 feet, and the limiting span, or modulus, is 1050 feet.

$$\text{Then } \frac{170 \times 212}{1050 - 212} = 43 \text{ tons.}$$

Again, for the Birmingham roof, 5040 feet of roofing, calculated to carry 40 lbs. per foot, equals 90 tons; the span is 211 feet; the limiting span, as before, 1050 feet.

$$\text{Then } \frac{90 \times 211}{1050 - 211} = 23 \text{ tons.}$$

The actual weights are 44 tons and 25 tons, the difference in the Liverpool roof being due to the fact that both the tensile and compressive strains are less than 5 tons and $7\frac{1}{2}$ tons respectively. In the Birmingham roof the tension is greater, but the compression is considerably less, being under 4 tons. It will, of course, be understood that the modulus, or limiting span, is dependent entirely on the strain to which the metal is to be subjected.

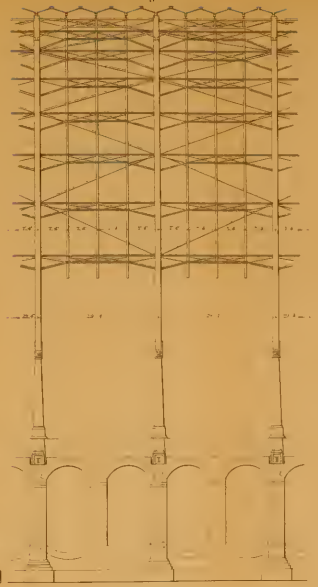
THE ST PANCRAS STATION.

MIDLAND RAILWAY.

Fig 1

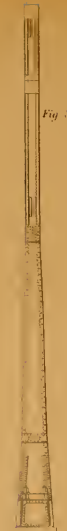
ELEVATION.

Fig 2



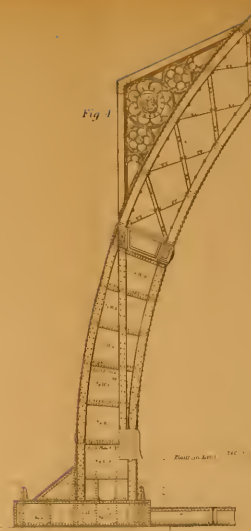
LONGITUDINAL SECTION.

Fig 3



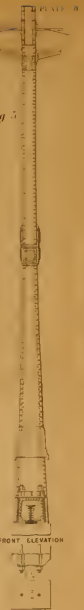
BACK ELEVATION

Fig 4



SIDE ELEVATION.

Fig 5



FRONT ELEVATION

THE ST PANCRAS STATION.

MIDLAND RAILWAY

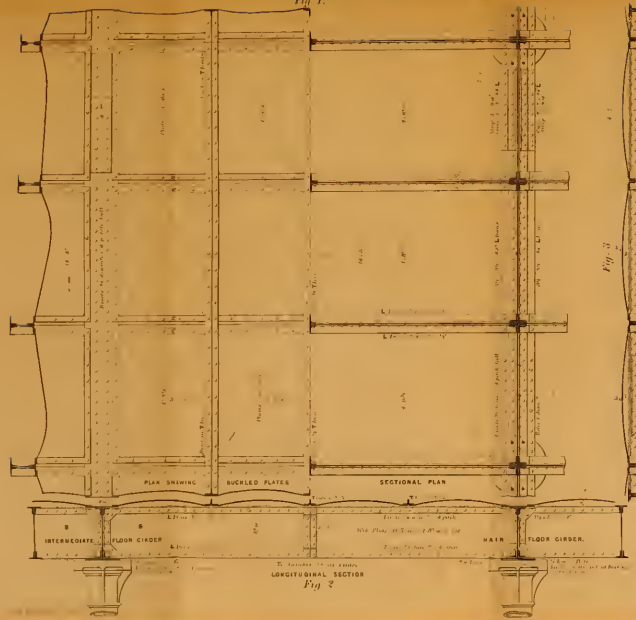


Fig 1.

Fig 2

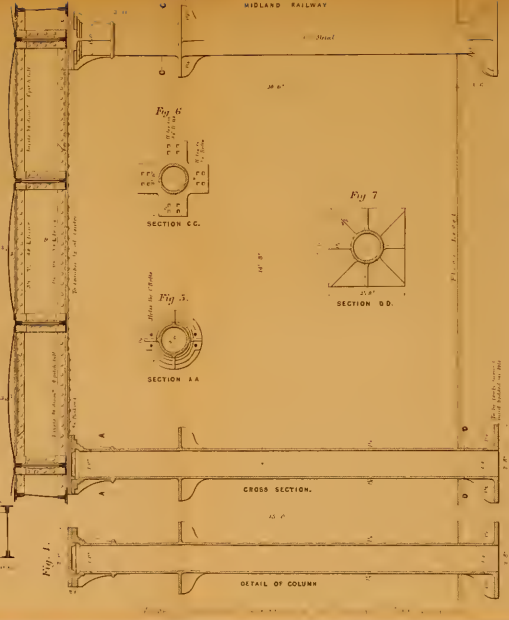


Fig 3.

Fig 4.

Fig 5.

Fig 6

Fig 7

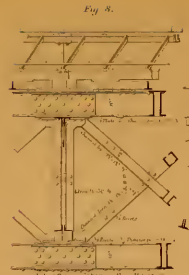


Fig 8.

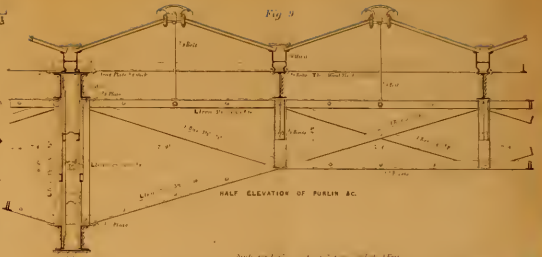


Fig 9

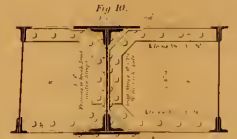


Fig 10.

Fig 11

Fig 12

The limiting spans above given for girders and suspension-bridges are calculated on the strains now generally used, thus differing to some extent from those arrived at by Professor Rankine, who has taken the strain of 3 tons per inch for dead-weight, and of 6 tons for the moving load.

The whole subject of the limiting spans of structures is well worthy of more study; for not only does it afford a test of structural value, but it enables the weight to be ascertained before the drawings for the work are commenced, so that any undue waste, either in the fastenings and connections or otherwise, can be readily detected.

The communication is accompanied by a series of diagrams, from which Plates 8 and 9 have been compiled.

Mr. J. J. Allport said that railway stations were frequently designed either with intermediate columns, or brick walls, varying in number of spans from one to five or six. In the course of a few years, it often happened that such stations had to be remodelled; platforms were wanted where lines of rails were laid, and *vice versâ*; and then the difficulty arose, how to accomplish the desired change without entirely reconstructing the station. In discussing the question with the Author, he had endeavoured to impress upon Mr. Barlow the desirability of having the station as free as possible from columns, or brick walls, though he did not at the time contemplate a roof of the kind which had been erected. He had also suggested to the Directors of the Midland Railway, that the whole of the station should be vaulted, knowing that the space so dealt with would be exceedingly valuable for the Burton beer traffic; and he believed it was that which first gave rise, in Mr. Barlow's mind, to the idea of having the roof in one span, and already the benefit of that arrangement had been experienced. For obtaining access to the vaults, it was originally intended to erect a hydraulic lift outside the western wall, so as not to interfere in any way with the lines of railway into the station: but subsequent inquiries showed, that it would have been inconvenient for utilizing the vaulting underneath, and it was resolved to erect a lift opposite the centre of the station at the north entrance. For obtaining access to that lift, two or more lines of rails were required within the station. If the station had been built in two spans, it was obvious that the centre walls, or columns, would have interfered with the proper use of the lift before the station had been opened eighteen months. The several lines of rails in the centre of the station might be continued to be used as lines of way, or might be replaced hereafter by platforms. There were five platforms at present, or rather five lines of rails alongside platforms, and two or more additional platforms could be constructed when needed. In the discussion which took place on the Paper "On the Design and Arrangement of Railway Stations," he stated that it was intended to place the offices in a certain position at the St. Pancras Station.[1] His remarks, with regard to the position of the booking-offices, were at that time severely criticised; but experience had proved that the booking-offices were in the proper position. There were already three platforms running the entire length of the station, and the platforms were easily accessible from the booking-offices: whereas if they had been placed at the centre of the buildings, as in most cases, passengers would have experienced the inconvenience of being obliged to go half the length of one platform to get to any of the others.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 284.

With reference to the colouring of the roof of the St. Pancras Station, he had done all he could to prevent the dark brown colour being used, which made it look exceedingly dull and heavy, and in his opinion marred, to some extent, the grand appearance which the station would otherwise have exhibited. He thought the colouring of a roof ought, as much as possible, to be made to represent nature; and he certainly never saw a sky the colour of that roof—not even when it was cloudy. He had discussed this matter with Mr. Barlow and Mr. Gilbert Scott on several occasions, and he believed the latter had come round to the opinion, that the colouring ought to be different from what it was. He was struck with some remarks which were made at a recent meeting of the Society of Arts, when a Paper was read on Surface Decoration, and the question of roof colouring was touched upon. The Author of that Paper said, Nature never erred; and that in colouring walls Nature should be imitated as closely as possible. When the sky was cloudy, it was a light white colour, or pale grey; naturally it was a beautiful blue, sometimes tinged with tints of vermilion and gold; he was quite satisfied if Mr. Barlow had adopted those colours in the roof, it would have presented a far finer appearance to the eye than it did at present.

Colonel Rich said, while he considered the St. Pancras Station the best terminus in London, there were two points which he thought might be improved in future structures. One was that the strain at the apex of the ribs should be the same as that at the springing. If that were so, the roof would be lightened considerably, and might be made similar to all arched structures; besides it would improve the appearance of the building, as well as cheapen it in construction. The other point was the manner in which the feet of the principals had been fixed. The process here resorted to was analogous to that of underpinning a building, when there were no other means of preserving a building whose foundations had failed. He thought the brickwork of the side walls should have been brought to a proper level at first; and the springing parts of the ribs, having been properly made, should have been set on them, and the whole rib started from a fixed and true point, instead of being suspended and adjusted by blocks and the wall afterwards built up in the same manner as in underpinning. Having said this he would add, that he considered the structure as a whole was a very fine one. He agreed with Mr. Allport that the colouring of the roof had somewhat injured the general effect, as when he saw the building in an initiative state, its appearance was more striking than it was at present; but that was a matter which could be easily remedied.

Mr. J. W. Barry remarked that there was one element of importance in discussing whether a roof should be of a single large span like this, or of two smaller spans; that was, the value of the

land over which the roof was erected. If the value of the land was high, as in London, he thought it would be found economical to build a roof of large span; whereas in the country, where land was comparatively inexpensive, smaller spans would probably be a better investment. He had calculated the cost per square foot of the land at the Cannon Street and the Charing Cross Stations, and he found that at Charing Cross the land cost £2·92 per square foot, and at Cannon Street £3·78 per square foot. If it was assumed that the loss of space, due to the use of columns, in the ground occupied by the columns and in the extra clearance required on each side of them wherever they were placed, amounted to 4 feet in width throughout the whole length of the station, the loss of land at Charing Cross would be found to amount in value to £8,176, and at Cannon Street to £13,852; and if to that was added the cost of the columns, say at Charing Cross £960, and at Cannon Street £1,260, then the cost of the columns and the land occupied by them would together amount at Charing Cross to £9,136 and at Cannon Street to £15,112. Now the whole cost of the principals at Charing Cross was £9,700, and at Cannon Street £21,898: so that in the one case it would be necessary to save almost the whole cost of the principals, and in the other three parts of the cost to make it good economy to erect the roofs in two spans. It was quite clear that, where land was bought at £3 or £4 per superficial foot, it was economical, irrespective of the inconvenience of columns, which were always an obstruction, and prevented the rearrangement of the station, to have only one span, and so utilize every inch of the space which was acquired at such an enormous outlay.

His experience of the value of cellarage in London had proved to him that it would have been an error to have filled up with earth the space available for cellars at St. Pancras. He had stated on a previous occasion, that the cost of the works up to formation level, exclusive of bridges over the river and over streets, on the Charing Cross and the Cannon Street railways, and other similar works in London, might be estimated to produce nearly 5 per cent. per annum on the outlay, by the rental which would be obtained by letting the arches and basements up to that level.[1] That assertion was questioned; but he had since investigated the matter more closely, with the following results. The substructure of the Charing Cross Station, the whole of which was not yet let, exclusive of the part occupied by the public footway, &c, cost £37,500, and the rental amounted to £2,000 per annum, which was more than 5 per cent. on the expenditure. The substructure of the Cannon Street Station, exclusive of the bridge over Thames Street, &c., had cost

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 481.

£50,000, and, although little more than one half was let, yet the rental at the present time was £2,500 per annum, being already 5 per cent. upon the cost of the works. The works to formation level of the main line of the Charing Cross railway, south of the Thames and up to the London Bridge Station, exclusive of bridges over roads, and the space not available for commercial purposes, cost £117,000. The arches were not yet all occupied, but those already let produced a rental of £5,500 per annum, which was nearly 5 per cent. on the cost of the substructure. That accorded with what he had stated before; and if he took credit for those portions not yet let, the result would more than substantiate his statement, that metropolitan railways on viaducts through crowded thoroughfares would pay in rental interest on the cost up to formation level, and that the railway did not cost anything in the long run, except for the space it occupied, the bridges over thoroughfares, and the works above formation level. He therefore thought the expenditure in cellarage at St. Pancras was most judicious, and he had no doubt the rental would approximate to what he had stated.

Mr. G. H. Phipps said he had recently considered those features in particular designs of roofs which would appear naturally to regulate their economy. When the spans of the spaces to be covered in were alike, and the principals consisted of ordinary trusses, such as those at Cannon Street, Charing Cross, or the Brighton Railway Company's portion of the Victoria Station, it was evident that, so far as the main compressed and extended members of the trusses were concerned, the deeper they could be made the better; but the economical limit of depth on this construction was soon reached, in consequence of the necessary increase of the weight of the angular struts, &c. It would appear, therefore, that any system, such, for instance, as that at St. Pancras, by which the relation of the depth to the span could be largely increased, while avoiding the necessity of angular struts, ought, on the above simple consideration, to be an economical system. There were, however, circumstances which modified the above general conclusion, consisting chiefly of the larger measure of strain which might safely be placed upon the compressed and extended members of trussed principals, than that to which the iron in an arched construction should be subjected, owing to the divergence of the curve of equilibrium from the axial line of the arch, when acted upon by the variable force of the wind. The Author had assumed 2·65 tons per square inch as the average pressure on the arch of the St. Pancras roof, where, on the trusses of the other roofs referred to, double that pressure, or 5·3 tons on the square inch, might no doubt be safely reckoned upon. The point to be examined, therefore, was, how far the increase of depth in the St. Pancras arched system would make up

for its deficiency in the coefficient of pressure considered safe to be employed. It appeared that the depth considered as a truss, down to what was termed in the Paper the springing, was about 78 feet, with effective span to the axial line of the rib at that level of 234 feet, being in the proportion of 1 of rise to 3 of span. The proportion of the depth to the spans stood thus in the following examples:—

——	Span.	Depth as a Truss.	Proportion of Depth to Span.	Proportionate Strain, per sq. in.
	ft. in.	ft. in.		
St. Pancras	234 0	78 0	1 to 3	1·00
Cannon Street	190 5	30 0	1 to 6·35	1·72
Charing Cross	161 9	20 0	1 to 8·08	1·83
Victoria, two of	120 0	12 0	1 to 10	

Supposing the iron in each of the three first whole spans to be capable of bearing the same strain on the square inch, and calculating on the principle that the strain, and consequently the weight per unit of length, was directly as the square of the span, and conversely as the rise, then the figures given in the last column would represent the relative cost per unit of length of the iron portion of the structure; but since the pressure per square inch at St. Pancras could only be taken at one half that of the others, the expense per foot of length would come out at 2·0, 1·72, and 1·83 respectively. The additional cost of the pedestals, on that portion of the ribs at St. Pancras which were beneath the level of the skewbacks, no doubt was considerable.

As regarded divided spans, as at the Victoria Station, it appeared to Mr. Phipps, notwithstanding the economy due to the reduction of spans while the ratio of height to span remained constant, that the small proportion of height to span of the trusses in the above cases would, other things being equal, naturally lead to additional expense. The introduction of columns at St. Pancras would have been particularly undesirable, even if the general arrangements would have permitted it, on account of the great depth to which they and their foundations must have been carried. The very high rate of loading, 70 lbs. to the square foot on plan, allowed by Mr. Barlow, with so small a coefficient of pressure as 2·65 tons to the square inch, had naturally led to an excess of expense in the roof of the St. Pancras Station, over others where a much lighter measure had been calculated upon.

Mr. C. Markham concurred in the opinion that the advantages of a station of this description were very great. Railway managers

had found great difficulty in the rearrangement of platforms, to meet their constantly increasing traffic. The principle of making a roof in one span which was not embarrassed by columns was of great importance. He hoped the station would not be defaced by pasteboard advertisements on the walls. One of the most celebrated architects in Europe had produced a structure which was a credit to the country and the railway system, but the moment it was completed, advertising boards were placed upon the walls. He was at first somewhat disappointed with the effect produced by the roof, but he admired it more every time he saw it. He agreed with Mr. Allport that the colouring might be improved. He had always taken a great interest in the structure, having been acquainted with Mr. Barlow's views from the first conception of the design. He was at a loss to understand why Colonel Rich complained of the mode of erecting the work. It was immaterial how a building was constructed so long as it was perfect; and seeing that when the ribs were put up only a trifling deflection had taken place, it must be regarded as a most successful mechanical achievement.

Mr. Allport said, in explanation, that the station was built for commercial purposes; and inasmuch as the advertising boards yielded to the Midland Railway Company £1,000 a-year, he did not think they could be blamed for allowing them to be put up. They were all of a light colour, and, in a great measure, relieved the roof from the dull appearance it would otherwise possess. If the colour of the roof were altered, perhaps the Directors might be induced to do away with some of the advertising boards.

Mr. J. M. Heppel remarked that the excess of cost in constructing this roof in one span instead of in two spans appeared to be about £6,000; but, considering the greater convenience afforded by the single span, that extra expenditure was fully justified. Besides, the great mileage and the large capital of the Midland Company rendered the expenditure on this head a matter of infinitesimal difference, in respect to the value of the consolidated stock; and it stood in singular contrast to the question, recently discussed, of the capital expenditure on the São Paulo railway. There, no doubt, a wise discrimination was exercised in adopting a mode of construction which involved less capital expenditure. In the latter case the whole vitality of the enterprise was involved; in the former, to have effected the saving mentioned would have been a piece of parsimony for which Mr. Barlow would have had the thanks neither of the public nor of the shareholders.

As to the mechanical features of the structure, he thought when it was stated that one of the conditions was, that the outline of the truss, between its two principal top and bottom members, should include all the lines of pressure, it might be imagined from the context that it was only to be carried down to what was called the

springing, where the open work ended; because any line that passed at an angle of 55°, which was stated to be the inclination of the lines of pressure at that point, in whatever way it might be included in the springing base, must pass outside the base of the whole truss. This would induce what was called usually a bending moment, or transverse strain; and the connection with the bottom would be more than that of a simple truss and its tie. The strong and substantial construction which went through what was called the tie, and also the foot of the truss, forbad the idea of danger to be apprehended from that. He nevertheless thought this part of the structure had something else to deal with than what was merely conceived in the relation between the abutment of an equilibrated arch and the tie. There appeared to be a discrepancy in the Paper, the truss being treated as if it were of the full depth down to the tie, and afterwards the different trusses were dealt with as if extending down to the springing only.

One question, with regard to the limiting span, had been brought forward, which was worth more study than was usually bestowed upon it. He believed, if carefully investigated, there would be in limiting spans a modulus for determining the relative structural values of various types of construction; and also, of checking particular designs in any respect, the limiting span being once ascertained from good designs of that type.

Mr. J. W. Grover said that being engaged at the present time in the construction of a roof of similar dimensions to the St. Pancras Station roof, he would offer a few remarks. First, he would draw attention to the point of rupture, which appeared to be immediately above the spandril. That would be more readily seen by conceiving the rib to be inverted and to be articulated, each of its sections being connected together by hinges. In that way a catenary curve would be obtained, and at the point immediately above the spandril, the angle of the line of pressure being 55°, which was straighter, there was a greater departure in the rib from this line than at any other point, consequently the rupture would take place there. He considered the roof a very beautiful structure architecturally; but he did not know on what constructive grounds the pointed crown of the arch was justified. Under any circumstances the pressure must be horizontal at the top, and it was stated in the Paper that that pressure was 89 tons, consequently the thrust at the bottom would be the same. With a tie to carry 89 tons, at $3\frac{1}{2}$ tons to the square inch, which he believed was the maximum pressure here admitted, a section of $25\frac{1}{2}$ square inches would be required, or allowing 10 per cent. for the rivetting a section of 28 square inches; that was the total section must contain 28 square inches of metal. This, on the length of 260 feet, gave 10 tons 18 cwt. as the weight of the tie. Now, if this was a bow

and string rib or truss, in considering the weight of the whole principal, the weight of the tie ought to be considered also. The weight of the principal was 54 tons 16 cwt., and with the tie added 65 tons 14 cwt.; the tie at a cost of £18. 10*s.* per ton came to a total cost of £201. 13*s.*, and this added to the cost of the principal gave £1,333. 17*s.* for the whole, or nearly £3 per square more than was stated. It might be said, that the tie was partially formed of the web and compression members of the floor girders, and that when those members were put in tension the strains were *minus* and *plus* and cancelled; but he thought the floor girders were continuous, and that the line of pressure would be alternately in the bottom and top flanges; therefore it was hardly possible to render available the whole amount of the tension that existed in all the members in compression. It might be said that the buckled plates formed one extensive section, and that they would, to a certain extent, meet all the requirements.

Another point for consideration appeared to be, that as the springing of the ribs was so near the ground, it was a question whether it would not have been worth while to have carried the whole roof 14 feet or 15 feet lower down, and made use of the ground as the abutment. If that had been done no tie would have been requisite, and the station flooring might have been constructed in imperishable brick arches; and assuming that those arches would have cost as much as the Battersea viaducts of 30 feet span, viz., £3 per square yard, the total cost would have been the same, and they would have been imperishable, instead of being of thin wrought iron which required to be painted, and was, comparatively speaking, of short life.

The weight on this roof was stated to be 70 lbs. to the square foot measured on plan, exclusive of the weight of the principals; but he thought it would be well worth while trying to get an accurate solution of what was the real weight to be taken in cases of this sort, because 70 lbs. to the square foot was, he believed, the weight allowed for the whole of the test weight on the Suspension Bridge at Clifton and on Westminster Bridge. If it was to be understood that the weight on this covering was equal to that of the passengers and vehicles on Westminster Bridge, it was a point which should be fairly established. He had never in his experience known such great weights come upon any roof. With respect to the weight of the principals, he had worked out the comparative weights with those of the Birmingham roof at New Street, taking Mr. Barlow's own rule, that the weight varied as the square of the span. The New Street Station roof at Birmingham had a span of 212 feet, and the principal weighed 25 tons. Comparing this with the one at St. Pancras, and allowing for the difference in the width apart, that

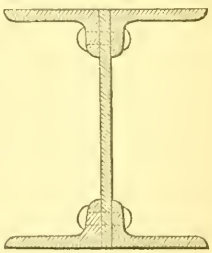
roof would weigh 41½ tons against 66 tons at St. Pancras—a very important difference, and one which was more considerable than at first sight would be imagined.

There was only one other point to which he wished to refer; that was the small amount of compressive strain allowed on the metal of the top: he could not understand why a strain of only 1¾ ton should be allowed for at the top when a strain of 3½ tons was admitted at the bottom. If the strains passed from the inside of the rib, there might be alternately compression and tension upon the flanges; and therefore one flange might be made strong enough to bear the whole tension, and the other strong enough to bear the whole compression. There were 46 inches in the whole rib, but it was possible, under certain circumstances, that one flange might be doing all the work and the other none; that was, the whole force might be on 23 inches. Although the wind had great effect upon these large roofs, he believed it had not so great an effect upon an arched building as it had upon an anemometer, or else some structures he knew ought to have been blown down long ago. In conclusion, he would repeat, that no one could look at the St. Pancras Station roof without feeling it was really a fine work; and he thought all must say, it was a structure creditable to this metropolis, to the railway company who owned it, and to the engineer who designed it.

Mr. E. A. Cowper said he thought Mr. Barlow intended that the true arch of the roof should begin from the tops of the plated parts of the standards, which were made fast by strong foundation bolts, not only to the bar, as that would not have been sufficient, but to the foundations; so that they were in fact like crane posts, capable of taking the horizontal thrust at their tops, and of thus supporting the true arch, which was of uniform, or nearly uniform section, as the strain of compression did not vary very much throughout the arch. Although the slight angle formed by the rib at the crown might appear objectionable, from the rib leaving the true curve of strain, this was not the case; for inasmuch as a catenary curve, which was the curve of strain in this case when the roof was equally loaded, had a sharper curvature at the crown than elsewhere, the slight angle in the rib at that place practically gave a sharper curvature, and the rib thus coincided with the catenary more nearly than it would have done had there been no angle. He found, on examining the form of the arched rib, that a catenary curve would pass within it, from the top of one standard or crane post to the top of the other, though at places it would be nearer the inside, and at other places nearer the outside of the arch; indeed, in the rib 6 feet in depth, it would be at about 2 feet from the side at the springing, and at about one quarter of the distance up the rib. With the load named by Mr. Barlow, the strain at the

springing was about 155 tons, and at the crown about 104 tons. The lines of strain of the arch, if continued, would fall outside the feet of the standards, so that they could not have been made simply into parts of the arch proper, or they would have crippled the arch, from not being in the line of strain.

As the roof over the Birmingham station, as well as the price of other roofs, had been referred to, he might remark that although the span of the roof of the New Street Station at Birmingham was 28 feet less than that of the St. Pancras Station, it was of greater total area, and was still the largest roof in the world. The cost was so much lower than that of several other roofs, that he thought it only right to state why it was so. The price, including all extras and general work, was only £17. 15*s.* 1*d.* per square, including two gable-fillings. The contractors who tendered for the roof of the Birmingham station were left to send in what design they thought proper, the plan of the ground only being given; and there was an idea that the price must be very low. However, when he saw that the rails ran parallel only in the middle of the station, where there would have been room for one or more rows of columns, but that they all 'fanned out' at each end from two or three lines of rails, and that at each end every part of the ground was traversed by engines and trains, so that it would be impossible to put any columns there, he considered that, as the ends of the station must be spanned, it would be best to span the whole with one bold roof, larger than had ever been attempted before; but that strict economy in the use of material must be carried through the whole structure. The rib itself had only two lines of rivets in it, and therefore the work was very economical, the angle irons being made unequal, so as to give prominent projecting flanges.[1] Then the rise of the rib being moderate, and the depth of the rib sufficient, a true catenary line of strain passed through it, and deviated but little from the centre line; and as the web was light, and most of the metal was arranged to be in the large unequal angle irons, the rib, considering its weight, was a very stiff one for withstanding compression, and was therefore very economical. The rib was kept in shape vertically by the diagonals between it and the tie-rod and queen-posts; and it was kept in line horizontally by the purlins and wind-ties, so that it could not bend or cripple, except by giving way by compression, between two queen-posts. The tie-rods were more econo-



Section of Main Rib of Roof of the New Street Station, Birmingham.

[1] *Vide* Minutes of Proceedings Inst. C.E. vol. xiv., p. 255.

mical for the work they had to do, than tie-rods generally. The covering was made of corrugated iron, on the score of economy. If it had been constructed of wood and slates, several shillings would have been added to the price per square, and the weight of the purlins and principals would have been rather greater.

One element of cost in which the Birmingham roof lay under a great disadvantage was, that it was taper, and not only of one taper, but of two different tapers. However, the arrangement he had carried out in the Tithebarn Street Station roof, in Liverpool, where there were more than sixteen hundred dimensions, had been carried out in this roof, where there were two thousand one hundred and sixty-four dimensions. The principals were all similar, though of different spans, and the largest and smallest principal in one taper having been drawn out, the plan was adopted of taking the longest and the shortest dimensions of any part, and dividing the difference by the number of bays of principals, so as to get the length of that part for each principal. This plan would not answer unless the principals were similar. Any variation in the angles, or attempt to keep the ridge level, &c., would be fatal to the arrangement. When this plan was adopted, a full table should be drawn out of all the dimensions, and a copy of all the dimensions of any particular part should be kept for the workmen making such part; and every part should be numbered conspicuously with the number of the principal it belonged to. No difficulty would then be found, and very little extra cost would be incurred, though the parts of one principal would not fit any other principal. One of the principals of the roof had been proved with a load of 40 lbs. per square foot, besides its own weight, and one-half and three-quarters of this weight had been successively removed from one side, to exaggerate the effects of the similar pressure which would come from a lateral gale of wind. That roof had, since it had been put up, supported the weight of a fall of snow about 2 feet deep.

Mr. Barlow, in reply upon the discussion, drew attention to the line of pressure in respect of the springing. Mr. Grover stated that the line of pressure, with an inclination of 55°, would come outside the structure; but Mr. Grover had omitted to consider the weight of the wall, the effect of which turned the line of pressure downwards, so that, in point of fact, the curve of pressure was really brought to about the centre of the foot. It had been truly said that the brickwork and ironwork, together with the holding down bolts, acted as a rock up to the point where the springing of the arch began. It had been argued that if a tie had to be made, and a pressure of $3\frac{1}{2}$ tons to the inch put upon it, at a cost of £18 per ton, the ultimate cost would have been greater; but the tie was there to begin with, and it gave rise to the roof. There was a certain amount of strain in it; but he believed, in

consequence of the arrangements, the strain on the tie was really very small. As to the colouring of the station, he would only say that he had adopted that colour which would least show the dirt from the smoke of the engines. It was true there was an excess of strength in the crown of the roof, if the vertical strains coming upon it were alone regarded; but when the lateral action of a roof of this construction, not bound by ties, was taken into consideration, it would be seen that there was a danger of its getting out of form, and that the strength in the crown was not only an advantage in that respect, but that it rendered unnecessary the introduction of various patterns of channel irons. Colonel Rich had animadverted on the mode in which the work was underpinned for the abutment. He believed the principle which had been adopted in that respect was the best. The large foot was set in its place at one operation. It was put up by timber packing and adjusted, and the brickwork was built up to it in blue bricks set in cement. He was led to adopt that plan from what was done in the case of the anchor-plates of the Clifton suspension bridge, where he had to deal with a greater strain than he ever had before, or probably would have again. The arch was turned from side to side of the rock, the anchor-plate was put in position, and the work was built up in blue brick and cement. The result was perfect stability with any strain that came upon the plates. He found the same result at St. Pancras; and he believed underpinning, as it was called, was the best possible mode of constructing a solid bed for a large iron base.

Mr. Vignoles, President, said the only point on which he would say a word was in respect of what was called the tie. Practically there could not be any strain; for, independently of the peculiar construction, it was supported at a vast number of points, which themselves tended to divide the strains, if there were any; and these would be less than was theoretically supposed.

April 5, 1870.

CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

The following Candidates were balloted for and duly elected:—John Bailey, William Elsdon, Alexander Kendall Mackinnon, and Thomas Fothergill MacNay, as Members; John Anstie, B.A., John Collins Boys, Thomas Cargill, James Robert France, Henry Gaerth, David Gravell, Stud. Inst. C.E., George Edward Grover, Lieut. R.E., Frank James, Joseph Kincaid, Henry Ernest Milner, Thomas Newbigging, Ernest Bengough Ricketts, Frederick Warburton Stent, Edward John Tatam, and Clarence Edward Trotter, Stud. Inst. C.E., as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—James Hills Blake, Massey Bromley, B.A., John Henry Eykyn, Alfred Fyson, William Gilchrist Gilchrist, James Henry Greaves, Hilin William O'Neale Neale, William Patten, and Charles Graham Smith.

No. 1,280.—"The Dressing of Lead Ores." By Thomas Sopwith, Jun., M. Inst. C.E.

The Author's first intention, in undertaking a communication on this subject, was to endeavour to give a general description of the mechanical appliances employed, and of the construction and action of several machines invented, many of them within late years, and of which, strangely enough, considering the immense importance of the mineral industry of the British Islands, no printed collective account is at this time extant. The last, if not the only, communication on the Dressing of Ores, on the records of this Institution, was by Mr. James Henderson, Assoc. Inst. C.E.[1] This was read in February, 1858; and since then no other has been made, either on the subject generally, on any branch of it, or on any particular machine. Since that time so many new applications have been brought into use—particularly in Germany, where this branch of mechanical engineering is immensely in advance of what is the case in England—that it is altogether impossible to treat the subject generally within the limits of one Paper, unless by

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., pp. 195-212.

giving a brief enumeration of different machines, of little interest and of less value to a scientific institution, or to practical men. The Author will therefore limit himself to a description of some works he has had occasion recently to erect, for the mechanical preparation of lead ores, and to an account of the results there obtained, which he thinks show some advance upon the methods and machinery usually employed in English lead mines. It will be his aim to detail the results of actual experience, rather than to give a cursory and incomplete account of a number of machines, which could hardly come within the range of the actual trial and practice of any one individual.

By Dressing is to be understood the art of obtaining from the raw material, drawn from the mine, called Bouse or Mine stuff, the pure mineral it contains, to the rejection of the impurities with which it is associated. The Mine stuff, as extracted from lead mines, may be said to contain, in an ordinary way, from 5 per cent. to 25 per cent. of galena. Pure galena, or sulphuret of lead, which is the ore of lead most commonly found, almost indeed the only one of commercial importance, has a specific gravity of 7·75, and contains 86 per cent. of metallic lead. The lead ores of commerce are usually dressed to a tenour of from 74 per cent. to 78 per cent. If argentiferous, they are generally delivered with a lower percentage; first, because, on account of their greater value, it is not desirable to risk loss in successive processes of concentration; and, secondly, because argentiferous ores are invariably more intimately associated with mineral impurities, difficult of separation, than ordinary lead ores. In England argentiferous ores are understood to be those which contain more than 12 oz. of silver in each ton of lead. The best and purest lead is, as a rule, obtained from the ores which contain least silver. No galena is found without more or less silver, and the richest in Great Britain is that of Cornwall, which contains commonly from 30 oz. to 40 oz. of silver to the ton. The separation of this silver from the lead does not come within the range of dressing operations, being effected by a subsequent process to that of smelting.

In dressing, all the applications of machinery act on the principle of separating, by means of their readier gravitation, the heavier particles of lead from the lighter ones with which they are associated. This is easy enough when the stuff treated consists of ore and fluor-spar, calc-spar, quartz, or any other impurity of much less specific gravity: but it becomes difficult when the ores are intimately blended with iron, copper, zinc, or other minerals having a specific gravity little inferior to that of galena; and still more so when such substances are also of marketable value, and where from the mine stuff several marketable products are to be obtained.

It may not be out of place to state that, in most mineral mines,

two systems of paying the miners are in use—one called 'tribute' in the South of England, and 'bingtale' in the North of England, by which the men are paid so much per cwt., ton, or bing (a measure peculiar to the North of England, weighing 8 cwt.) of clean ore their work produces; the other 'tutwork,' or fathomtale, where the men are paid by the amount of excavation made by them. The former system is inconvenient for dressing operations, as after each parcel produced by the several partnerships, or sets of miners, is washed up, the different apparatus must be stopped and emptied, —a measure not necessary when the latter system is employed.

In this Paper frequent allusion will be made to the amount of work which can be passed through different apparatus. As this varies according to the nature of the stuff treated, and particularly as it is more or less rich, some standard, as representing ordinary average mine stuff, must be adopted. This the Author fixes at about 12 per cent. (weight) of ore, of Mine stuff, or of Bouse treated, being equal to what in the North of England would be called worth $2\frac{1}{2}$ bings per shift; a shift being eight wagons of a size in general use there, carrying of such work a load of about 1 ton each.

At the works now to be described, about 350 tons of lead ore are produced monthly. There are two distinct dressing-floors, the higher and the lower. (Plate 10, Figs. 1 and 2.) The operations which will be described on the former do not differ in principle from those commonly practised in England; although modifications of form in the apparatus used have been introduced with considerable advantage. These will be pointed out, but as a matter of detail, as they will be of interest rather to those actually engaged in mining operations than to engineers generally. On the higher floors (Fig. 1) the mine stuff is first treated, and such separation as can be effected without the need of crushing is made; on these manual labour is principally employed. The stuff is separated into clean ore, waste, and a third class, where the ore and the waste are united in the same pieces, and which must be reduced to a smaller size, by means of crushing, or breaking, before they can be separated. On the lower floors (Fig. 2) is treated the stuff, which passes through the crushing mill. It is more particularly the machinery and the method used on these floors that it is the purpose of this Paper to describe.

Fig. 1 shows, in plan and section, the arrangement of the higher floors, on which from 200 tons to 220 tons of lead ore are produced per month, or nearly two-thirds of the entire quantity. The mine stuff, drawn from the different galleries of the mine, is delivered into wagons at the shaft-top, which convey it by a tramway to the teams, A. By preference mine stuff of similar nature will be kept together in the same teams.

The washing operations on the higher floor commence by turning a stream of water into the teams A. The first separation is made at what is called the 'grate' B, which is of cast iron 3 feet long and 2 feet broad, with horizontal spaces 1 inch wide. As a rule one grate only is employed, with spaces $\frac{3}{4}$ inch wide, but the Author has found advantage and economy in using two, thus providing more grate surface for the pickers, one as described, and the other of similar size placed inferior to it, with spaces of $\frac{1}{2}$ inch each. The sides of the grates are planes, sloping inwards; they are of wood covered with sheet iron, $\frac{1}{8}$ of an inch thick. On them the operation of picking is performed by women and boys; a man stands at the top of the grate, and rakes stuff from the team into it; the small stuff goes through at once, and what remains is picked into the three classes already mentioned, and is at once conveyed in wheelbarrows or wagons to their destinations. Water is employed to facilitate the raking out, to carry the small stuff onward until it is deposited in the trunk D at the bottom of the second grate, and to clean the larger stones left on the grate, so as to simplify the operation of hand-picking.

The stuff which passes through the second grate is of a size convenient for hotching or jigging, the most important operation used in Dressing, as a large proportion of the mine stuff treated is subjected to it. In England from 25 tons to 30 tons is a fair day's work to pass over one grate. It has been found, from actual measurement, that the double grate used in the works described is capable of dressing about 40 tons of Mine stuff, or Bouse, per day.

On the floors in question, the labour employed, and the wages paid, are as follows:—

	In Spain.	In England.
	s. *d.*	*s.* *d.*
1 raker in	1 8	1 6
4 pickers (women), at 10*d.*	3 4	3 4
1 picker (boy)	0 10	0 10
1 boy wheeling away	1 6	1 2
1 boy at stirring trunk	1 0	0 10
2 hotching, at 1*s.* 10*d.*	3 8	3 0
Share of round buddle cost	2 0	1 6
	14 0	12 2

From stuff containing therefore 12 per cent. of ore, upwards of 4 tons 16 cwt. would be obtained from 40 tons, at a cost of 2*s.* 11*d.* per ton of clean ore in Spain, or 2*s.* 6*d.* in England.[1]

In mines worked in England on the bingtale system, the same

[1] In this, as in other comparisons, the Author states, in addition to the amount of wages actually paid in Spain, that which would be paid in the mining districts of England for similar work.

stuff would cost 7*s.* 6*d.* to 8*s.* per ton of clean ore, the difference in cost being partly owing to deficiency of grate surface, and partly to each parcel requiring the whole apparatus to be emptied on its termination, and in many cases to the grate being erected at a distance from the teams, the stuff being conveyed from the latter to it in wheelbarrows.

Between the lower grate and the sludge-trunk is the stirring trunk, C, into which all the stuff enters which passes through the lower grate. Here, with a roller fixed at the lower end as a fulcrum, a boy agitates the stuff with a shovel, to expose it as much as possible to the current of water, so as to relieve it of any particles of sludge, which would greatly impede the action of hotching, and when clean takes it out, placing it alongside the hotching-tubs, the smaller particles or sludge being carried over into the sludge-trunk.

The common hotching-tub, K, or sieve, consists of a plain rectangular tub, nearly filled with water, in which works a rectangular sieve, with close sides and an open wire bottom. This tub is suspended at each end from the short arm of a lever, the longer arm of which is moved by a boy up and down with a springing motion, each jump being accompanied with a jerk, which assists the separation of the particles contained in the sieve. The hotchings (*i. e.*, the stuff to be hotched) are filled into the sieve to a depth of about 8 inches. It is then 'hotched' for about a minute (more or less, according to the richness and nature of the stuff). The long end of the lever is next depressed, held by a catch, and the sieve thus raised out of the water. The top part of the stuff contained in it is then 'skimped' off with a flat piece of sheet-iron, held by both hands, into a wheelbarrow or wagon, as waste. More stuff is now filled in, and the same operation is repeated until the sieve is nearly full, when, besides cleaning off the waste, the matter next to it, called technically 'chatts,' consisting of particles with lead and some impurity united, is also separated, and afterwards the pure ore is found nearest to the bottom, ready for delivery into the ore stores.

One hotching-tub can treat from 8 tons to 15 tons of stuff per day, allowing for stops for taking out smiddum.

To render the chatts marketable further subdivision is necessary, and on most washing-floors a separate crushing-mill, adapted for fine crushing, is provided.

At the bottom of the hotching-tubs, the ore which passes through the coarse wire bottom of the sieve accumulates; this is called smiddum, and generally contains upwards of 40 per cent. of lead, and is often nearly pure. To enrich it the buddle, E, is used. This is a plane slightly inclined, made of either wood or of iron, and about 6 feet wide by 5 feet long. A stream of water is let in at the

top, and the smiddum is drawn gradually in small quantities across it, the operation being repeated until all the light particles have been carried away.

The sludge deposited in the sludge-trunk, D, Fig. 1, is emptied about twice a day, and is removed to the round buddle, F. It is filled into the apparatus at *g*, where it is well broken up with knives fixed on a revolving axle. Water is also admitted, and with the sludge passes through a rotating cylindrical wire-work sieve (10 holes to 15 holes per lineal inch), which separates and delivers apart at *m* any chance piece of stone or lumps of sludge insufficiently broken up, chips of wood, and in Spain the bits of esparto grass (which cause much trouble) proceeding from the common use underground of esparto-grass baskets for conveying the ores, and from the sandals worn by the miners, which are made of the same material. The work which passes through this sieve is conveyed by the water to the centre of the round buddle in a launder, for which an inclination of 1 in 10 is sufficient.

The following modifications in the form of buddle usually employed in England have been introduced. The diameter has been increased from 18 feet to 21 feet, and the centre, usually a tapered cone about 12 inches at the bottom and 6 inches at the top, is a plain cylinder 2 feet in diameter; and in place of two revolving arms with suspended cloths sweeping along the top of the stuff being dressed, making three to four revolutions, two revolving sprays are employed, making seventeen revolutions per minute.

Too limited an area in the centre seems wrong in principle, the velocity of the incoming water on so small a surface preventing the proper deposition of the heavy particles. No difficulty has been experienced in keeping the surface smooth (the object for which the cloths are employed); and by the use of sprays the velocity of the water is more regular over the whole area, and does not decrease so rapidly as when the only water is the incoming water at the centre. In the sprays clean water is used, delivered by a small launder into a funnel on the upright axle.

Of the stuff delivered at the centre the heaviest particles are first deposited, the operation going on until the buddle is full to a depth of about 20 inches, when the water is drained off. The stuff at the inner part, to a distance of 4 feet from the centre, called the 'heads,' will be found enriched from say 12 per cent. to about 40 per cent.; this is separated. The next lot, containing about 12 per cent., is also separated for retreatment with the next parcel of work from the sludge-trunk, and the stuff at the outer circumference is wheeled away as waste, none of it probably containing more than 1 per cent. of ore. The 'heads,' on a sufficient accumulation, are treated similarly, and can be enriched by a second operation so as to produce from 70 per cent. to 74 per cent. If the

sludge presents difficulty for separation the operation would be repeated a third time.

The diameter of the buddle is . . .	21 feet.
The diameter of the centre	2 ,,
Number of revolutions of sprays . .	17 per minute.
Number of revolutions of sieve . .	17 ,,
Number of tons treated[1]	8 tons to 10 tons per hour.
Inclination of bottom	1 in 10.

The bottom is made of cement in preference to wood. The buddle is turned by a small water-wheel of about $\frac{1}{3}$ H. P.

The water which passes away from the sludge-trunk and the plain buddle, and also from the hotching-tubs (when they are emptied), contains fine slime (not without ore) in suspension, and is conveyed by drains to the slime-pits, which are shown at G. The slimes are treated in a machine called the Brunton's cloth, shown at H, and in detail on Plate II., Figs. 8 and 9. The cloth, which is of coarse canvas stiffened with paint, is strengthened and kept level across the face by laths of elm a few inches apart. It is held in a frame which is inclined about 1 in 6, the inclination being adjusted by suspending screws at the bottom, and passes over rollers fixed at the top and the bottom of the frame. The cloth moves upwards at a rate of about 15 feet per minute. The slimes are well broken up amongst water and are delivered on to the cloth at *h*. A stream of clear water at *i* has sufficient force on the inclined surface of the cloth to carry away the light particles; the greater adhesion of the grains of ore enabling them to withstand it, and remain attached to the cloth, until dipped into the tank below, when they fall to the bottom.

There are, therefore, three adjustments for treating different natures of stuff, viz., inclination of the cloth frame, rate of movement, and quantity of clear water admitted. The apparatus as generally used is fairly efficient, and its construction is within the reach of the staff ordinarily employed in mining works. Its efficiency is increased by the addition of a slight percussion motion in many of the German washing floors; but this improvement is not yet general, and is not applied either in England, or in the works now being described.

The first time of treatment in this machine suffices to enrich the

[1] Round buddles in common use in England are stated to treat about 2 tons per hour, the revolving arms making only $2\frac{1}{2}$ to 4 revolutions per minute. The quantity stated by the Author, 8 tons to 10 tons per hour, is the result of the following experiment:—

The buddle commenced to work at 8 A.M., and at 10·20 A.M. was full to a depth of 21 inches. The mean diameter occupied by the stuff was $18\frac{1}{2}$ feet, and deducting the space occupied by the centre, 403 cubic feet were found to be contained, weighing on an average 123 lbs. per cubic foot, equal to 25 tons 8 cwt., which were passed through in $2\frac{1}{3}$ hours, or at the rate of about $10\frac{1}{2}$ tons per hour.

stuff treated to about 45 per cent., the waste matter being carried away from the tail of the apparatus. From the fact of the stuff so treated being mixed with water, it is not easy to say what quantity can be passed per day; the machine is so nearly automaton, that a slight return pays all costs; a boy at 10*d.* per day being all the *main d'œuvre* required. It is found with one such machine in the higher slime pits, and another on the lower floors, that from 5 tons to 6 tons of ore are obtained per month, worth from £10 to £12 per ton delivered in England, at a cost of about £3, say 10*s.* per ton.

The enriched slimes of 45 per cent. are passed through the dolly tub—a cylindrical tub, about 3 feet in diameter at the top, and 3 feet deep, tapering towards the bottom, and nearly filled with water. The stuff as thrown in is kept agitated by revolving a fan inside, and when a sufficient quantity has been introduced, it is allowed to settle, during which time the sides of the tub are knocked with wooden logs or hammers, giving a vibratory motion to the water, and tending to keep the particles apart, and prevent their adhesion in knobs. Slimes can be enriched to about 70 per cent. by this means.

The operations of the higher floors may be said to terminate here, and the Author will now proceed to explain the methods used in the lower floors, for the preparation of those minerals which require crushing. Previous, however, to doing this, he will explain, as briefly as possible, the form of crushing mill in general use in England (Plate 12, Fig. 1), so as to enable a comparison to be made with the machinery he has adopted. This is worked generally by steam or water power. The mineral crushed is passed to the hotching-tubs, and is subsequently treated much in the same manner as on the higher floors, with this difference, that in many cases, advantage is taken of the motive power required for driving the mill to attach a shaft from which to work the hotching sieves. The work to be crushed is delivered into the hopper *a*, passes through the rollers *b*, *b*, which are kept in contact by the pressure of a heavy lever *c*, loaded at one end, and falls into *d*, a cylindrical rotating sieve, inclined about 1 in 8, covered with coarse wire-work, which allows the mineral, when sufficiently crushed, to pass through, returning larger particles to the raff wheel *e*, which elevates them to a shoot, conveying them to the hopper *a* again. The whole of the crushed material is passed through a stirring trunk, making a partial separation of the sludge previous to its being treated in the hotching tubs.

A strong building is required, owing to the height at which the rollers are placed above the ground, and from the strain caused by the heavy weight suspended from the lever (frequently about 15 cwt. to 20 cwt. suspended at a distance of 9 feet to 10 feet from

the fulcrum), which is in continual and violent motion when the mill is at work.

The hotching machinery usually employed acts by giving to the sieve an up and down motion by means of cams or levers; another lever being applied in either case to raise it out of the water, when it requires 'skimping,' serving at the same time to throw it out of gear.

The preceding description applies, except in the particulars to which attention has been drawn, generally to the operations in common use in English lead mines. That, as a system, it is mechanically defective, is evident at first sight. In support of this assertion, the operation of hotching may be instanced. Here, for the supply of one tub, a boy is required to lift from the stirring trunk about 15 tons of stuff per day, which he deposits in a heap between the trunk and the hotching-tub; whence it is from time to time again relifted into the sieve (a height of about 3 feet), and is thence again emptied, by hand, after being hotched, either as waste, chatts, clean ore, or smiddum, and delivered into wheelbarrows, to be removed to their several destinations. There are, of course, many other machines in partial, and some in general use, which have not been mentioned, being beyond the scope of this paper. It is probable, however, that in the apparatus now briefly described, 80 per cent. of the lead ore sold in England is prepared.

In the lower, or crushing mill floors, next to be described, and which were erected some time after the higher floors already alluded to, some attempt has been made to secure continuity of action, by the use of self-acting machines whenever it was practicable—a principle, however, which, under the circumstances of Spanish labourers being employed, totally unaccustomed to the use of machinery of any description, was sacrificed whenever its adoption necessitated any complication of working parts.

The mine stuff, which requires crushing, is here treated. To become fit for the crushing-mill, it is reduced to a size which would allow it to pass through a 5-inch ring; and this is done by manual labour with hammers. It was under consideration to employ a stone-breaking machine for this purpose; but, besides extra cost in the first instance, extra power would have been required —a matter of no small moment when coal costs £3 per ton. Hand-breaking has also this advantage,—it enables a separation to be effected, first, of some fragments of pure lead ore, and secondly, of a large quantity of poor stuff which would only afford unnecessary work for the crusher.

A stone-breaking machine, therefore, in this case, was not adopted, though the Author, from what he has seen of it elsewhere, is of opinion that in the case of large quantities of hard mine stuff,

with ore intimately associated with other mineral matters, it would be a desirable, if not a necessary adjunct to well-laid-out dressing establishments.

The general arrangement of the crushing-mill dressing-floors is shown on Plate 12, Figs. 5, 6, and 7. The stuff to be crushed is conveyed by wagons, and emptied into the hopper *a* of the crushing-mill. When crushed, it is elevated by D, an endless-link chain with buckets (called the Jacob's ladder), and delivered into a classifying trommel C, which returns to the crushing-mill all the particles which are too large for the hotching-machines, separates all the sludge which is considered too small for hotching, and delivers in another direction the material of proper size and condition for machine-hotching.

The crushing-mill (Plate 12, Figs. 2, 3, and 4) is too simple to require description. It is more compact than the form usually employed in England, and any degree of compression can be given to the rollers by means of the caoutchouc buffers, which are equally effective as heavy weights and levers. The rolling-surface is of chilled iron, made as a ring, which is kept on the roller-shaft by three wedge-bolts. The diameter of the rollers is 37 inches, the breadth 10½ inches, and they make eight revolutions per minute. The velocity of the rolling surface is therefore 77½ feet, and the crushing area of each roller is 68 square feet per minute. This form of crushing-mill is self-contained, requires scarcely any foundations, and absorbs less working-power in friction than the form used in England; and the working parts are few, easily dismounted, and can be readily manœuvred. The shafts carrying the rollers are geared with toothed wheels at each side. One roller, therefore, does not work by friction only, as in many mills in this country. By being geared, a better 'grip' is secured, and the action is altogether more steady and regular. The toothed wheels have teeth unusually long, so as to keep in gear when the rollers become separated by the passage of some large and hard stone, or other strain tending to separate them, which may be sufficiently powerful to overcome the compression of the india-rubber springs.

With the rollers in fair order, from 5 tons to 6 tons per hour can be treated of stuff averaging in hardness ordinary mountain limestone, broken up, as already explained, to a size which would pass through a 5-inch ring.

No difficulty has been experienced from the use of the caoutchouc springs, even during the summer, when working in a temperature of 90° in the shade. One set has lasted about two years, and with care should serve as long again.

The wear of the chilled rollers is very variable. Steel ones are occasionally used, and answer very well, and their use would doubtless become general but for the expense. From four to

eight months is the general time of service, representing, say, 5,000 tons to 10,000 tons of material crushed by the chilled rollers the Author has used.

In considering the action and duty required of a hotching-machine, it must be evident that the separation, by gravitation, of the several matters treated in such a machine must be greatly facilitated, when the particles are of uniform size, otherwise it is clear that a large piece, say, of iron pyrites, would gravitate more quickly than a small one of lead ore; for, whereas the weight increases as the cube, the surface opposed to the resistance offered by the water is only as the square of the side of particles of similar form. True, in the English system lead has been satisfactorily dressed without sizing; but it is principally because lead, for the most part, is raised from veins, where the accompanying impurities are of much less specific gravity. There would be no difficulty, either, in showing that even in those cases the dressing operations would be improved and performed more economically by the use of sizing apparatus, which is simple and efficient, and inexpensive both in first cost and future working. For the application of sizing to be efficient in the treatment of ordinary ores of lead, it is by no means necessary to employ such elaborate arrangements as are in use in Germany.

The number of classes adopted by the Author was considered by the German manufacturer much too few. They have, however, given good results, and are as follows:—

Of the material crushed, all which will pass through a perforated plate with round holes of $1\frac{1}{2}$ millimètre is treated in buddles. All particles which will not pass through a perforated plate with round holes 10 millimètres in diameter are returned to the crusher. All the material to be hotched therefore is clean shingle (to adopt a new term in dressing), which is separated into the following sizes:—

		Millimètres.		Millimètres.
No. 1, which will not pass through holes	$1\frac{1}{2}$	in diameter, but will pass through	$2\frac{1}{2}$	
„ 2, „ „	$2\frac{1}{2}$	„ „	5	
„ 3, „ „	5	„ „	7	
„ 4, „ „	7	„ „	10	

The classification is thus effected: the material having passed through the crushing rollers is raised by the Jacob's ladder, and delivered into the first trommel C, which is constructed of an outer shell of perforated iron with round holes $1\frac{1}{2}$ millimètre diameter, and an inner shell of stronger iron with round holes of 10 millimètres diameter. A perforated pipe, parallel to the outer edge of the trommel, conveys jets of water to facilitate the separation. The *work* after entering progresses naturally onwards and downwards; the sludge passes through the inner and outer shells, and is conveyed in an iron launder to B; the particles insufficiently crushed

arrive at the lower end of the trommel, and, dropping into the buckets fixed in the circumference of the inner trommel serving as a raff wheel, are lifted up and delivered into a shoot with sufficient elevation to carry them to the hopper again. The largest quantity, however, goes by a second launder to the trommel E, supplied with water in a similar manner to the first one; an inclination of 1 in 15 is sufficient to give onward motion to the material being treated. It is equally divided into three classes, the first being covered with perforated plates, with holes $2\frac{1}{2}$ millimètres in diameter, the second 5 millimètres in diameter, and the third $7\frac{1}{2}$ millimètres in diameter; and the stuff falls through one or other of these divisions, or is carried over the end to their respective compartments, whence it is taken to the hotching-tubs, each tub being adapted for the size it is intended to treat.

The hotching-machines employed are entirely self-acting (Plate 11, Figs. 1, 2, 3, 4, 5, and 6). Instead of the sieve moving, as in the common one previously described, it is stationary, and the water is set in motion by a loosely fitting piston *a*, Fig. 4, which at each pulsation raises all the stuff in the sieve. The relative positions of the several particles naturally change at each stroke, the heaviest or purest particles of ore eventually being brought to occupy the bottom. The stuff is delivered by boys into the hopper *b*; the bottom of the sieve is level, but the new stuff falling from the hopper, gradually displaces that in the sieve, causing it to move forward. On reaching the end of the sieve, a distance of 28 inches, a perfect separation is found to have taken place; the lighter particles are at the top, and at each pulsation of the machine some are carried over the shoot into the waste launder. The heavy ore is at the bottom, a depth of $1\frac{1}{2}$ inch to 2 inches being generally occupied by it. Apertures properly regulated admit the ore into the cistern *c*; a broad flap of sheet iron *d*, Figs. 2 and 4, is regulated by the man in charge to such a distance from the bottom as is found to pass the ore only, and an upper flap *e* and apertures serve for the exit of the chatts. The size of the apertures is also regulated at will by means of a slider *f*, Fig. 3, worked by a screw, which cuts off more or less of the holes as may be necessary. The machine is thus automaton and continuous in action, requiring but little attention, and preparing the lead to as high a standard as is necessary for sale. A fast and a loose pulley are attached to each hotcher. The ore and chatts are emptied from time to time from the cistern. One man and a boy are able to attend to four such machines. They could easily be made self-feeding; but in the works now being described, the additional machinery was not applied.

There is a peculiar appropriateness in the mechanical action of these machines, which merits attention. Formerly the piston was moved by an eccentric; the present motion is given by a

crank g, Fig. 6, of variable stroke working in a slot. The down stroke is given as the crank moves from h to i (Fig. 6); and as the crank pin revolves at a uniform rate, the down stroke during which the stuff is lifted is therefore quick, and the return stroke slow, allowing more time for the deposition of the particles. The stroke of the crank can be varied by moving the crank pin up and down a slot, the pin being fixed by means of a nut behind.

From experiments with different hotching-machines, it has been ascertained that the number of strokes per minute suitable for different sizes of work can be advantageously increased for the larger particles, while the length of the stroke is found to be of less importance, although this also has been similarly increased.

The machine for washing No. 1 size has a stroke of 1 inch, and makes 82 strokes per minute.

No. 2 size, a stroke of $1\frac{3}{4}$ inch, and 84 strokes per minute.
" 3 " " 2 " 86 " "
" 4 " " $2\frac{1}{4}$ " 96 " "

The machine for the finer stuff has a different movement, applicable more particularly to short strokes,—a revolving cam, as in Fig. 7, with buffer springs composed of well-prepared caoutchouc; its other details, as regards self-action, being similar to those already described.

The waste from each of the tubs is conveyed by the water which overflows with it along the waste launder underground to b, Plate 10, Fig. 2, and is there delivered into wagons (with perforated iron bottoms so as to allow the water to drain off) and wheeled over the waste heap.

The sludge which passes through the outer skin of the first trommel is delivered into a separator, B (Plate 10, Fig. 2), which consists of a cylinder with an annular space, formed by the insertion of an inner block, regulated in diameter according to the size of the work it is intended to operate upon. This is shown in detail in Plate 12, Figs. 8, 9, and 10. In this annular space a stream of water is constantly rising, brought by the supply-pipe a, of sufficient force to effect a separation, carrying the finer particles over the top into the launder, b, whence it is conveyed away for treatment in the round buddle and the Brunton's cloth, whilst the coarse and richer particles fall to the bottom, and are treated in sludge trunks (ties) of simple construction. (Plate 10, Fig. 2.) A stream of water distributed over the whole breadth of the tie is admitted; the sludge is filled in at the top with a shovel, being well distributed there, and exposed to the current of water; the heaviest particles settle first, and the lighter ones are subsequently removed; the heads resulting from the first operation are put aside, and subjected again to the same treatment. After being passed twice, or at the most three times through the tie, they are fit for market.

The other sludge which was carried upward in the separator is conveyed to the sludge-pits at F (Fig. 2) and treated by the round buddle, while the finer portion which does not settle there is carried by the water into the slime-pits at G, where it is taken out, and treated by Brunton's cloth, both of which machines have been described.

The machinery employed is worked by one of Messrs. Ransomes, Sims, and Head's 10 H.P. portable engines.

The following observations on the amount of stuff treated have been made. The amount of work delivered to the crushing mill on an average during a day of ten hours is 1,100 cubic feet, or 55 tons. Of this quantity there is returned of [1]

No. 1 size	71	cubic feet.
„ 2 „	112	„
„ 3 „	220	„
„ 4 „	244	„

The quantity crushed produced 75 cubic feet of clean ore, weighing 6 tons 9 cwt., equal 6·82 per cent. in bulk, or 12 per cent. in weight of ore, which is perhaps a fair average of the work usually treated in the crushing mills of the principal lead mines in Great Britain.

The ore obtained was:—

	cwt.	cwt.		
From No. 1 hotcher . . .	20·50	= 28·87	per 100 cubic feet treated.	
„ 2 „ . .	23·18	= 20·70	„	„
„ 3 „ . .	30·05	= 13·66	„	„
„ 4 „ . .	20·30	= 8·32	„	„
Sludge (tie and round buddle)	45·39			
Slime, Brunton's cloth . .	1·58		„	„
	cwt. 141·00.[2]			

In instituting a comparison as to the cost of ore dressed by the machinery just described, it is obviously unfair to take as a basis the number of hands employed and the wages paid in Spain, where labour of this kind is neither good nor cheap. Although the Author gives what is actually paid there, he thinks that a comparison with results obtained in England should be based upon the number of hands which would be employed there, and the wages they would obtain in mining districts.

[1] The quantity of sludge and slime cannot be estimated, as there are no means of measuring them, mixed as they are with water; nor is it possible to ascertain the difference in bulk which is due to the 1,100 cubic feet on being crushed into smaller fragments.

[2] These are Spanish cwts., or quintals, of which there are 22 in an English ton.

The following is the labour actually used, and that which would be required in England:—

In Spain per Day of 9 Hours.	£.	s.	d.
1 feeding crushing mill	0	2	0
1 master washer	0	2	6
1 assistant to ditto	0	1	8
1 ditto at trunk	0	1	8
1 assistant	0	1	6
3 filling hotching-tubs, at 1s. 6d. each.	0	4	6
2 round buddle	0	3	0
1 Brunton's cloth	0	1	0
1 wheeler of waste	0	1	8
1 odd man	0	1	8
	£1	1	2

In England per Day of 10 Hours.	s.	d.
1 feeding crushing mill at 10d.	0	10
1 master washer	3	0
1 assistant	1	3
1 ditto at tie	1	0
1 assistant	0	8
2 filling hotchers, at 1s. 3d. each	2	6
1 round buddle	0	9
1 Brunton's cloth	0	9
1 wheeling off waste	1	6
1 boy (odd man)	0	9
	13	0

Giving totals respectively of 21*s.* 2*d.* for day of 9 hours, and 13*s.* per day of 10 hours, which might be still further reduced to 9*s.* 6*d.* by substituting self-feeding machinery in place of the fillers in, to hotching-tubs, and of the assistant employed at tie.

Thirteen shillings as the labour cost on 55 tons of raw material treated throughout the floors gives 2·83 pence per ton, or on 6 tons 9 cwt. 2*s.* per ton of clean ore produced. In like manner, taking instead of 13*s.* as the labour cost the reduced sum of 9*s.* 6*d.*, the labour cost will be found to amount to 2·07 pence per ton of raw material crushed, or 1*s.* $5\frac{3}{4}$*d.* per ton of clean ore produced.

The total cost including motive power is not given; in many cases water power could be applied. For nine hours' working in Spain, from $6\frac{1}{2}$ to 7 cwt. of Newcastle coal are burned. The Author believes that the labour cost per ton of clean ore produced in England with crusher and machine hotchers (English system) is about 2*s.* 6*d.* per ton in treating stuff of similar conditions, also exclusive of the cost of motive power.

The cost of erection of the crushing mill floors complete, including water-conduits, machinery, buildings, and 10 H.P. engine, was about £1,500. The same machinery if erected in England would not have exceeded £1,200.

The crushing mill, shafting, sizing trommels, and crank lever-movement of hotchers were made in Germany by Messrs. Sievers and Co., of Kalk, near Cologne. The tubs, which are of wood, were made on the mine, but the iron tubs as made by Messrs. Sievers are in every way preferable. The self-acting apparatus was invented in Germany about four years ago, and first introduced practically by (the Author believes) Mr. Max Braun, Engineer-in-Chief of the Vielle Montagne Co., to whom the Author is indebted for the design of those described, and now used by

him, as well as for much valuable information on dressing. On his dressing floors nearly every improvement of late years can be seen in operation.

It will be observed that no description of the subsequent treatment of the 'chatts' has been given. In a general way, they would be passed to a fine crushing mill, and after being crushed would be dressed in fine hotching sieves and round buddles. With a view to simplify the machinery, this addition was not applied. The crushing mill already described is more than sufficient for the current work of the mine, and the 'chatts' are allowed to accumulate, until a time when the crushing mill is not required, in which spare time a week or two's constant crushing (the bottom of the sieve and the stroke of each hotching machine being varied) with a pair of new rollers will dispose of the accumulation of eight or ten months.

It may be thought an omission not to have introduced stamping apparatus. The Author believes, even for the most refractory lead ores, that stamping apparatus is out of place, the work being more economically and more efficiently done by crushing rollers of large diameter, and with good crushing surfaces.

Great attention was bestowed, and many experiments were made, on the subject of passing as much work as possible through the several machines described; the result was the adoption, in every machine, of a higher speed of working than what is usually employed, with satisfactory results. These experiments cannot be detailed here, but every statement of rate of working and of the quantity of stuff treated, applied to the different machines, is from actual observation during regular working.

The Author regrets having to conclude this Paper without a description of Zeuner's, Hunt's, and Borlase's buddles, of many ingenious slime-separating apparatus, of Rittinger's side-table, of the shaking-table, and of other machines comparatively modern in their adoption. It cannot be said, however, of any of them that they are in general use, and with them can be mentioned at least a score of different mechanical appliances, more or less employed in dressing operations in lead mines.

The Author must apologise for so incomplete a description of dressing of lead ores—incomplete as a whole, and incomplete in its parts; he has only been induced to make it, seeing how scanty information has as yet been supplied from the branch of the profession he has adopted, either on this or other matters belonging to it.

It cannot but be a matter of regret that the surface operations and mechanical appliances of most mines in Great Britain should as yet have attracted so little attention from educated engineers, and that, as in dressing, the appliances should be of a

nature within the reach of the mine carpenters and blacksmiths to manufacture. Abroad engineering establishments employing as many as four hundred hands are dedicated almost exclusively to the manufacture of dressing machinery, and it is not surprising to find in the machines issued there better proportions, more elegance of form, and greater durability and efficiency than in those used in home mines.

In Germany improvement in dressing machinery has doubtless been more a necessity than in England, the veins of minerals being, as a rule, poorer, and more intimately mixed up with matters difficult of separation.

An argument is sometimes used against replacing manual labour by machinery, that as men are required for underground labour in the mines, some labour should be provided for their children to prevent their leaving the district. It may be doubted whether on the whole there is much profit by employing boys under twelve years of age, and as they are fit for many purposes underground at sixteen, there should be no difficulty in employing the boys ranging between those ages. It may also be fairly expected, that with more perfect machinery, dressing operations would be further elaborated, and much poor stuff might be treated which is now neglected.

It should always be remembered, also, in considering these operations, that the ultimate cost per ton of ore produced is not the only point to be attended to; the quantity of ore obtained from the gross quantity contained in the mine stuff is the real point of interest. In neither hemisphere, probably, can more imperfect appliances than those used in many Spanish mines be found. The Spaniards have, however, implicit faith in them, and point out that for their monthly production, say 100 tons of ore sold, the washing or dressing has not cost more than £5 during the month; although possibly with decently arranged floors 120 tons, instead of 100 tons, might have been obtained from the same mine stuff.

The Author believes that the washing-floors he has described will compare favourably with any now in use in England. He must, however, say he does not hold them up as a model to be imitated, and would hope to see considerable advance made upon them, should similar machinery be erected under more advantageous circumstances. The circumstances under which the machinery in use on the lower floors have been erected will be allowed to be unfavourable. The machinery comes from a distance. There is no foundry or fitting shop, in which to make repairs, within one hundred miles. The personnel available for working it is utterly unaccustomed to the care of machinery, and, as a rule, not fond of improvements, or alterations. These conditions obliged the Author in his first design to make simplicity the leading feature, and sub-

THE DRESSING OF LEAD ORES,

GENERAL ARRANGEMENT OF HIGHER AND LOWER FLOORS

PLATE 30

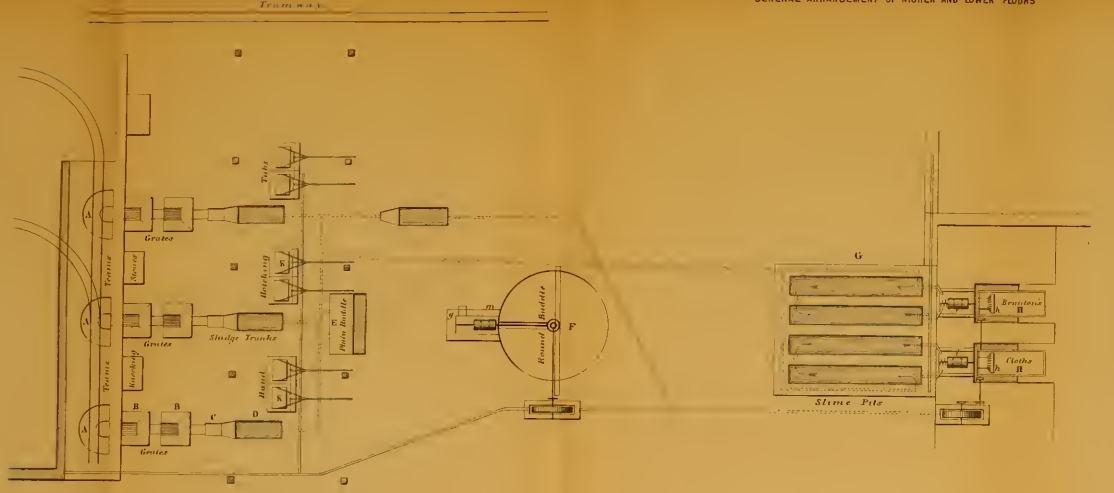


Fig. 1.

Scale ½ Inch = 10 Feet.

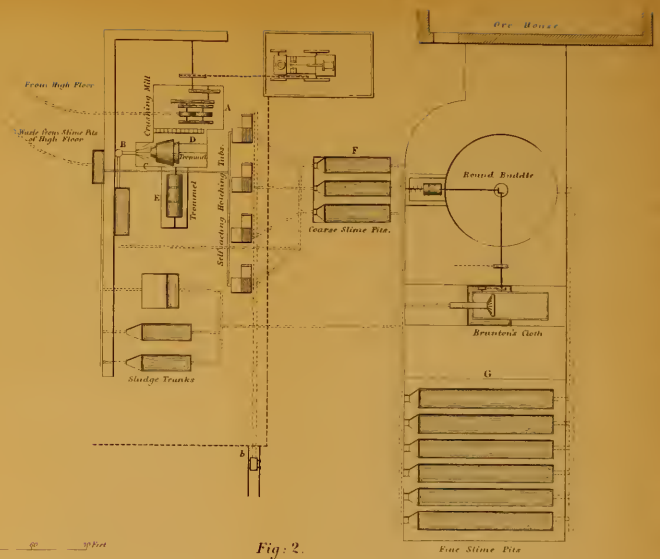
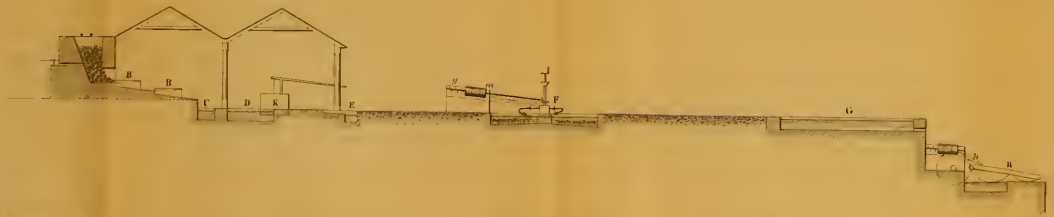
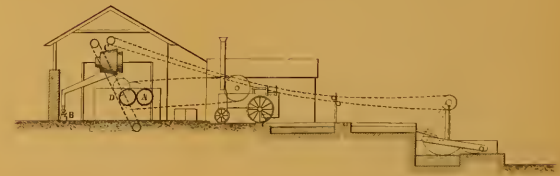


Fig. 2.





THE DRESSING OF LEAD ORES.

DETAILS OF HOTCHING MACHINE.

Fig. 1.

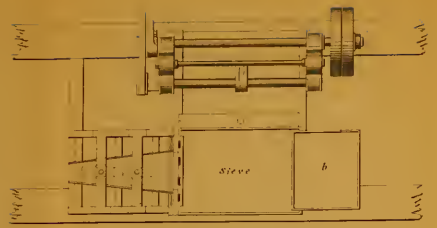
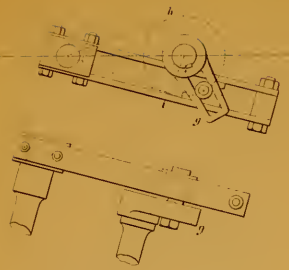


Fig. 6.



ENLARGED DETAILS OF CRANK MOTION.

Fig. 7.

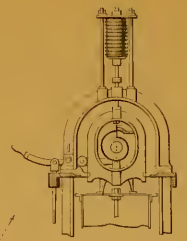


Fig. 8.

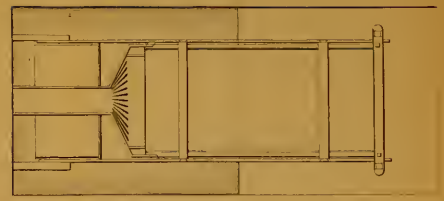


Fig. 2.

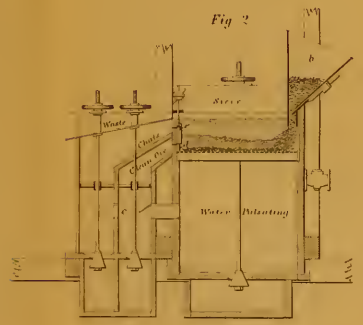


Fig. 3.

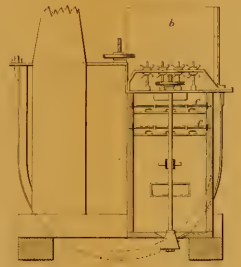


Fig. 4.

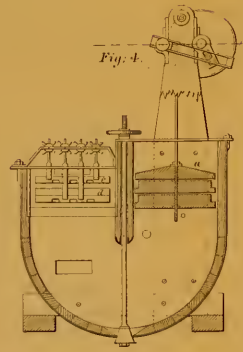


Fig. 5.

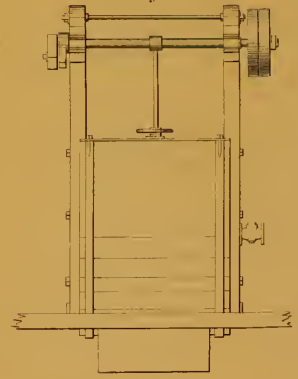
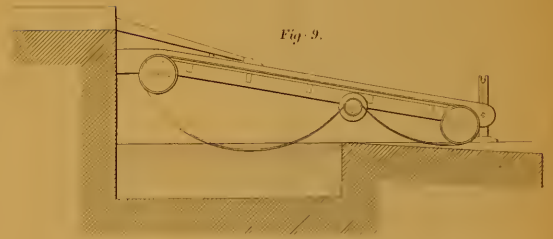


Fig. 9.



BRUNTON'S CLOTH.

Scale ½ Inch = 1 Foot

0 ½ 1 2 3 4 5 6 Feet

Scale ½ Inch = 1 Foot.

0 ½ 1 2 3 4 5 6 Feet

THE DRESSING OF LEAD ORES.

DETAILS OF CRUSHING AND DRESSING MACHINERY.

PLATE 32

Fig. 1

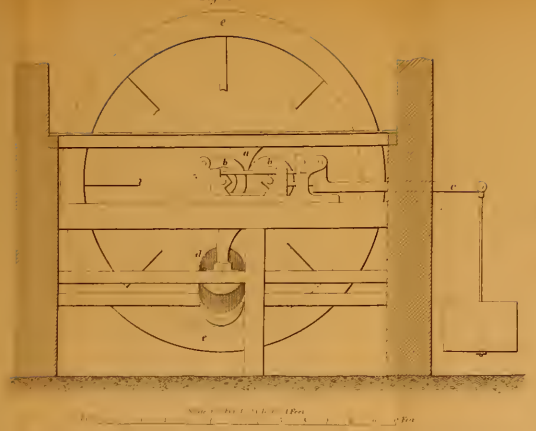


Fig. 2.

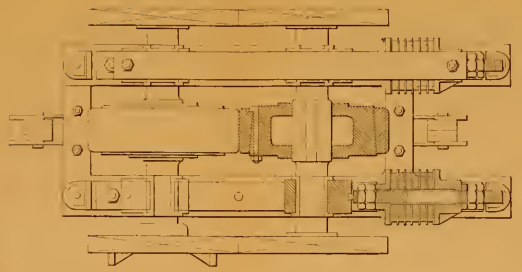


Fig. 3.

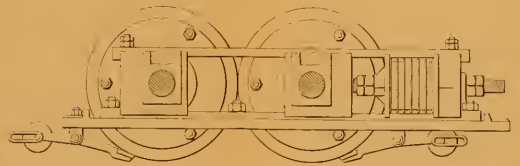


Fig. 4

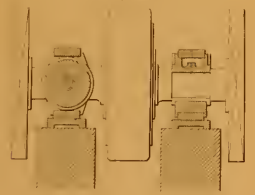


Fig. 5.

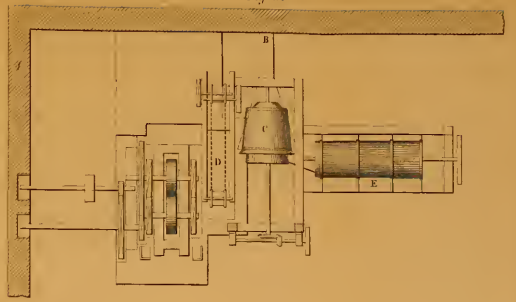


Fig. 6.

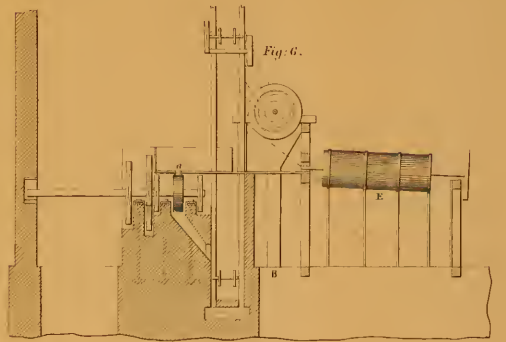


Fig. 8

Fig. 9

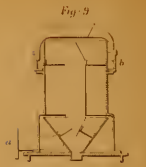


Fig. 10

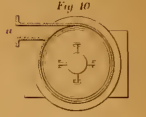
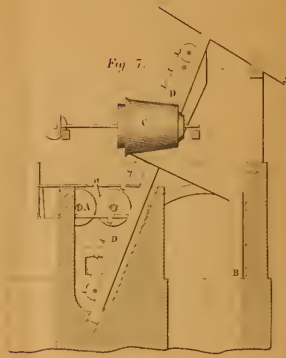


Fig. 7.



sequently even to make many departures from it, in order to obtain still further simplification. The expense of fuel, and consequently of motive power (£3 per ton), also limited him in the application of machinery. And, lastly, the ore, when clean, is, comparatively, of less value than it would possess in England; thus ores, which in that district are worth from £7 to £8. 10s. per ton, would, delivered in England, command £12 to £14 per ton. The machinery on the lower floors has been in actual work for nearly two years, giving satisfactory results. No difficulty would be felt in working similar arrangements in any part of England, however unaccustomed the hands employed might be to the management of machinery.

The communication is accompanied by a series of diagrams, from which Plates 10, 11, and 12 have been compiled.

Mr. Warington Smyth observed that there was a difficulty in the peculiar nomenclature used in describing the operations, which was not very intelligible to people in London, nor even to the miners of many districts, the terms hotching, chats, and smiddum, having to be translated into jigging, raggings, and hutch-work, in Wales and Cornwall. These and other peculiar names were, however, employed for a series of every-day operations, very interesting in themselves when looked at in their real character, as a means of dealing with materials of various sizes, weights, and forms in suspension in water. The subject was so extensive that it would be unreasonable to expect a single Paper to deal with the entire matter. On the other hand, it might perhaps be asserted, that a mere description of a series of operations practised in one spot might be deficient in interest, and was not a subject on which any lengthened discussion could be based. Some years ago Mr. Henderson, of Truro, brought before the Institution a Paper descriptive of the operations in use in Cornwall, which, however, did not give rise to any considerable discussion;[1] but there were some points in the present Paper, though treating only of one locality, which touched questions of high importance to engineers connected with mining operations. He would leave the treatment of the materials, as they came from the mine, untouched, and pass to the grinder or crushing mill. This was a piece of machinery which took its rise, not a great many years ago, in England, and was transplanted to the Continent, where it had been improved by the mining engineers in point of efficiency in some respects, certainly in the common employment of rolls of larger diameter, in more exact sizing, and perhaps also in substituting springs for the long lever, which was generally in use in this country. He was surprised to find, on a visit during the last year to the Hartz mines, the extensive works which were being then carried out at Clausthal, where the entire plant of apparatus was upon the largest scale he had ever seen, and where all the crushing machines were made with the substitution of springs for levers.

The next point was the separation of the metal from the refuse, as carried out by the hotching or jigging machines. There was a good deal to be said about that process, and he thought the Paper was valuable in this respect—that it described a certain selected type from among numerous forms of this apparatus, and gave the actual results obtained in practice. He would only mention that this process started upon the simple principle of bringing materials of various forms and different specific gravities into contact with a volume of water, either by means of a plunger forcing a wave against the bottom of a fixed sieve, or by the dipping of the sieve

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 195.

suddenly into the water. The contrivances for effecting this were very varied, beginning with the sieve plunged into the water by hand, then going on to improved break sieves moved either by hand power or machinery, and passing to an apparatus, which was not mentioned in the Paper, but which deserved to be referred to, viz., the jigging-hutch with plunger and fixed sieves, which was introduced under the name of "patent separators" in Cornwall, forty years ago, by Mr. Petherick. That was a great improvement, and led to its being carried out further at the Hartz mines. It should be remarked that, for a great deal of the machinery applicable to these operations, English mining engineers were indebted to their former fellow-subjects, the Hanoverian miners, who were now swamped under the general name of Prussians. They had perhaps done more in the elucidation of the theory of the mining and dressing of argentiferous lead ores, and its reduction to practice, than the miners of any other country. He had been particularly struck at Clausthal with the application of jigging machines with a rapid but very light stroke, of $\frac{1}{2}$ an inch, to the rougher part of the sand from the stamps, the passage of the material being continuous.

It was a North German variety of this class of machinery, the working of which had been brought before the Meeting. It was manifest that, in comparison with the intermittent action of the old jigging machines, a continuous action of the kind described must be very valuable, and he thought he might say that in practice nearly three times more work was got from it than from any apparatus which required stopping and clearing by hand. But he should like to hear an accurate comparison between this particular apparatus, which had sprung into existence in the Hartz mines, and certain other kinds brought forward in Przibram and elsewhere. He believed experiments on a large scale had established the advantage of jigging with a piston below instead of on one side of the sieve, and good results had been obtained from what had been called a jigging pump, the piston being provided with valves above, and having a series of valves placed below it, to allow an equable passage of the water through, which tended to carry the material away in one direction, and without undue waste of water to secure a continuity of delivery.

He would say a word with respect to another class of apparatus, viz., the trommel for the sizing of the particles. Revolving riddles had been employed in many cases in this country, but not with the same general care and accuracy as in Germany. At the Devon Consols mine-apparatus of this kind was employed for the sizing of the particles of copper ore. With respect both to this and to the jigging operation, English miners were becoming alive to the importance of introducing this principle of continuity; and within the last few months a new machine had been introduced by

Mr. Remfry, of Dolgelly, in various mines in Wales, and had been found of great value in separating zinc blende from the lead ore.

He passed on now to the apparatus for separating the finer particles of lead ore from the waste, viz., the round buddle. On this matter he thought Mr. Sopwith had hardly done justice to the miners of this country. He had taken a certain form, and claimed for it larger dimensions and greater efficiency than in that employed at home; but Mr. Sopwith probably was not aware that in Cornwall buddles existed of various diameters, and one at Wheal Owles, of no less than 50-feet diameter—a very gigantic apparatus, of which miners of the far western parish of St. Just might be proud,—did its work admirably, on the same principle as that referred to in the Paper. There were, however, in connection with this apparatus a good many questions yet unsolved. He was glad to see Captain Williams present, because he had adopted a new form of round buddle; and it was desirable to have the experience of a miner who differed *toto cœlo* from those who thought the material should be started from a wide base. It was commonly the case that, in buddles of ordinary diameter, there was a conical base of 2, 4, or 6 feet, and in others, of 9 feet in the middle. Furthermore, in conclusion, he would remind the meeting, that it was difficult to lay down a rule with great precision upon any one of these points, unless the character of the ore was known—not merely the nature and proportion of metal it contained, but also the other properties of the materials to be acted upon. It was not merely the percentage or hardness of the ores and associated spars, but there were matrices caused by differences of the country rock which gave rise to difficulty. Thus, in a general way, lead ores raised from veins which coursed through clay-slate contained, when crushed and mixed with water, so much slime, that it was difficult to rid the material from it, and therefore the same rapidity of manipulation could not be obtained in that case as from a vein of ore intersecting a granite country. In making comparisons, then, of results from different machines at different mines, it was important to bear in mind the varying classes of vein stone and the presence of heavy waste that was often mixed up with them. If such questions as these could not be readily settled, they might make an impression upon some present who had the opportunity of recording experiments on points of this kind, which were of a high degree of practical importance.

Mr. John Taylor observed that Mr. Sopwith had described the dressing apparatus and arrangements of a mining district where, as far as his experience of it went, everything was of the roughest and readiest kind. The ores of that district were generally extremely rich compared with those of most mines in this country. The gangue or admixture was of a light character. The specific

gravity of the ore and of the waste was widely different, and therefore the dressing was comparatively easy. He had never seen in England what he had observed in the south of Spain, owing to the absence of water, viz., the separation effected by a process like that of separating chaff from grain; and which could only be done in cases where the specific gravity of the waste or earthy matter was low.

The first machine to be noticed amongst those which Mr. Sopwith had described was the crushing mill. In his opinion the English machine with weights and levers was superior to that in which india-rubber buffers, or any sort of springs, were employed to compress the rollers. It was no new thing to use springs. He had seen them in America many years ago; but those springs, as applied to this kind of machinery, lost their elasticity and became useless after a short time; whereas the lever and weight system kept the rollers well together, and could be regulated to any degree that was required, and the material could be reduced to a fine size by its action. Subsequently, modifications had been adopted in the stone-breaking and crushing mills in America, some of which were shown in the last Exhibition in this country, and they had since been extensively adopted and used.

The number of hotching machines was very great in the United States, as well as in this country, copied almost invariably from the German models. Numerous small improvements had been made in them, first by one person and then by another; of these none was greater than that by M. Bérard, who obtained a gold medal at the Exhibition of 1851 for the excellence of his machinery for washing coal. Then there was, previous to M. Bérard's, the machine invented by Captain Petherick, giving action to the water by a plunger. This, combined with an arrangement for admitting a clear stream from beneath a fixed sieve, which carried off all the material and rendered it free from impurities, had led to improvements in a great variety of this class of machines. No people were more alive to their own interests than the English miners, but their great object was profit. In Germany the object was to give employment to as many people as possible, and to get out the greatest quantity of metal from the mines they worked. A desideratum in all mining machinery was the perfection of the apparatus which Mr. Sopwith had alluded to, viz., the trommel, for separating the mineral matters after being reduced to a small size, so as to have distinct quantities of the particles of equal size for further treatment. When that was done the rest of the process was comparatively easy, but the perfection of machinery in that respect had yet to be obtained. The German trommel and hotching machines were amongst the best, assuming it gave stuff of equal sizes, and that the particles were so different in specific gravity as

to make their separation and hotching easily practicable; but in many cases the mineral substances mixed together were so nearly alike in gravity as to render any dressing process extremely difficult.

Mr. J. Lee Thomas remarked that the extent to which dressing could be profitably carried depended a great deal upon local circumstances; and was much influenced by the supply of water that was available for carrying out the operation, the character of the matrix accompanying the ore, the degree of its dissemination through that matrix, and perhaps most of all by the value of the ore (when made marketable) at the mine. In this country galena of a similar character to that of the Linares district, and yielding by assay 78 per cent. for lead, was worth from £12 to £13 per ton, whereas at Linares itself it was worth only from 9 to 10 reals per arroba, or from £8 to £9 per ton; and, as a consequence, the operation of dressing could be carried further in this country than there. At the same time the dearness of fuel in the district referred to rendered it necessary that the ore should be dressed to a high percentage there—certainly not less than 78 per cent.—for this reason, that any slight additional expenditure, incurred in effecting this, would be more than covered by the economy realised in the after operation of smelting in the reverbatory furnace and subsequent reduction of the slags. Fortunately there was no difficulty in dressing the Linares ores to 78 per cent., because the gangue accompanying them was of a low specific gravity, viz., from 2·6 to 2·8, whilst the gravity of galena was 7·7; and with this great difference between the specific gravity of the ore and the gangue, the problem of their separation was relieved from the difficulties attending it in cases where the specific gravity of the gangue was high, as in the case of its being—

	Specific Gravity.
Sulphate of baryta	4·3
Sulphide of zinc	4·0
Carbonate of iron	3·8

He had always regarded the first operation in dressing, viz., that of grating the stuff from the teams or slides and its subsequent selection, or classification into qualities of distinctive size and richness, as the more important one of the whole process, inasmuch as any solid ore getting improperly classed with earthy matter in this operation, and passed on to the crusher, led to a great loss in all the subsequent ones; indeed it could not be too much insisted upon, that the finer the stuff was reduced, the greater was the percentage of loss. He thought therefore that the Author of the Paper had acted judiciously in using two grates instead of one. In lieu of the second grate he preferred a revolving riddle, or trommel, 5 feet long and 1 foot 6 inches in diameter, making

from 20 to 30 revolutions per minute. An apparatus of this kind was used at Messrs. John Taylor and Sons' mines in Cardiganshire. The stuff that did not pass through the wirework of the riddle was ejected from it on to a rotary picking table, making one revolution in four minutes, around which were placed four children, who classified the stuff ejected into firsts, seconds, and waste. A more extended classification might be adopted if circumstances pointed it out as desirable.

As to the size of the spaces between the grate bars, or the size of the holes in the riddle, that was a matter of detail, and would vary at different mines from 1½ inch at some to ¾ inch or less at others, and was dependent, in a great measure, upon the degree of dissemination of the ore through the matrix. It was impossible to lay down any fixed rule, as to the quantity of mine stuff that could be passed through a grate in a day. If the stuff came from what was technically called a dawky or stiff clayey lode, from 20 tons to 25 tons per day was as much as could be properly treated at one grate; but if, on the other hand, the vein stuff was of a free sandy nature, there would be no difficulty in putting through 40 tons a day. As regarded the crusher described in the Paper, he agreed with Mr. John Taylor that the English apparatus with levers and lever-boxes was preferable to that with springs, as in the case of an unforeseen obstacle, a piece of iron for instance, having to pass the rolls opening them in its passage 3 inches or 4 inches, with springs there must be a violent recoil, whereas with levers properly arranged there was comparatively no recoil; besides, with levers there was practically uniformity of pressure; and with springs that could not be, for the wider the rolls opened the more intense became the pressure given out by the springs. Uniformity of pressure was wanted, and certainty of pressure, and the latter, with the lever arrangement, was easily adjusted by taking weight out of, or putting it into, the boxes. A pressure of 6 tons or 7 tons on rollers 27 inches in diameter, and 15 inches wide, might be used when nearly solid galena had to be crushed, but would be found insufficient if the stuff crushed contained a large proportion of tough quartz rock. In that case an effective pressure on the rolls of 10 tons or 11 tons would be required. These or greater graduations of pressure were easily obtained with the lever arrangement, with the additional advantage of knowing exactly what the pressure was, which was uncertain with the india-rubber spring arrangement, as the buffers might fail, and must vary in their action from day to day, more especially in a country where the variations of temperature were so great as they were in Spain.

As regarded the continuous hotching machine, which he considered as the chief feature in the Paper, with free stuff like that operated on at Linares, and classified in size as that was, there

could be no question of its answering; but he should like to see it tried with gangue of a high specific gravity. If the result were favourable the machine might then be regarded as a great success.

With regard to round buddles he had used them making 18 revolutions per minute, those of Mr. Sopwith making 17. In the buddle he alluded to the centre was a truncated cone, the top diameter being 2 feet, the bottom 2 feet 10 inches, and the height 2 feet; these buddles got through a large quantity of stuff, but required a good supply of clean water. For dressing the finer slimes the Author of the Paper had adopted frames, which were more commonly applied in this country to the dressing of tin and copper ores, where the operation of dressing was carried to a great degree of tenuity. For dressing the fine slimes of lead ores, Zeuner's rotating buddle gave very good results, as the inclination of the table could be varied so as to suit the nature of the stuff treated; and if the apparatus were provided with speed pulleys, the speed at which the table rotated could be varied so as to effect a separation of most kinds of stuff.

With regard to the cost of these operations, according to the first estimate given in the Paper, 40 tons of stuff per day were dressed at a cost of 2*s.* 11*d.* in Spain, and 2*s.* 6*d.* in England—per ton of clean ore obtained. Now the Author fixed the standard of richness of the mine stuff treated at 12 per cent. by weight, and as 4 tons 16 cwt. of clean ore were got from 40 tons of material treated, the whole of its contents were practically obtained, so that the operation must be considered final. But he noticed that nothing was set down in that estimate for spalling and crushing; and as 8½ tons nearly of mine stuff had to be put through the grate to obtain 1 ton of clean metal, it might be fairly estimated that from 2 tons to 3 tons of this quantity would have to go to the spalling floors. Taking the quantity sent down to the spalling floors at 2½ tons, and the cost of spalling at 5*d.* per ton, 1*s.* 0½*d.* would have to be added to the estimate under this head. Again, calculating the quantity sent from the spalling floors to the crusher at 1½ ton, not an exaggerated estimate to set upon it, and the cost of crushing by steam power (with coal at £2 per ton) at 8*d.* per ton of stuff crushed, 1*s.* would have to be added for crushing, and this would bring the cost approximately to 5*s.* per ton of clean ore obtained.

He had found when in Spain, and the returns at the mines under his charge there were 500 tons to 600 tons of lead ore monthly, that the dressing cost was about 5*s.* 6*d.* per ton; indeed he thought it might be laid down in the majority of cases, that as long as the cost of dressing was confined within 3 per cent. and 5 per cent. of the value of the marketable ore, that it was kept within proper limits; but, in special cases, these limits would be exceeded; and

the circumstances in almost each case varied so much that no universal rule would apply.

He was specially interested in the continuous hotcher, and should like to see further investigations made with it in this country, as continuity in dressing operations was very much to be desired.

Mr. T. B. Jordan referred to the remarks of Mr. Taylor and others on the great importance of sizing. He was now engaged in the examination of copper ore belonging to the Cape Copper Mining Company, with the view of treating it by a self-acting jigging machine. This ore was delivered to him after having passed the crushing mill, and he separated it by sifting into six different sizes, commencing with a sieve of ten holes per lineal inch, and finishing with one of thirty holes per inch. These various sizes had each been carefully assayed for copper, and he found that the finest sand was the richest, from which there was a regular step by step diminution of value as the size of the grains increased. Of course the explanation of this was, the greater friability of the ore as compared with the gangue, or waste, and the fact thus definitely established by assay was the strongest evidence in support of accurate sizing; for assuming that several of these sizes were mixed and then passed over the jigging machine, it was certain that the finest particles of ore would be carried over by the same force of water requisite to move the larger particles of waste, and thus the richest stuff would be washed away, and only the larger particles of ore retained; whereas by treating the sizes separately, a much larger percentage of the whole quantity of ore was retained at a mere nominal difference of cost. That this was the result of the usual practice and want of attention to sizing was further shown by the fact that the ore above referred to was the refuse of a previous dressing process, and yet it was worth 5·25 per cent. of copper in the bulk, and that portion of it which would pass a thirty-hole sieve contained 8 per cent., while that which would not pass a ten-hole sieve contained 3 per cent., and required further crushing before it could be separated. There was a very marked distinction between the stuff above alluded to and that treated of in the Paper under discussion, because the ore and waste treated by Mr. Sopwith had widely different specific gravities, and were, therefore, easily separated, while this sample of Cape copper ore held much of its copper in carbonates and silicates, which were but slightly heavier than the waste with which they were associated; hence, a course of treatment which would be satisfactory for the former class of ore, would utterly fail with the latter.

Captain R. H. Williams said, that machinery was necessarily employed to separate tin ore from stuff that contained only $\frac{1}{2}$ per cent. of metal. In dressing tin ore it was found that revolving cloths were of little use. Increasing the diameter of the dead centre of the

buddle appeared to him inexpedient. In the treatment of 10 tons of stuff, it often happened that only 1 cwt. of tin was procured; and he contended that the buddle which would reduce that soonest into 1 cwt. of marketable ore must be the best machine for separating the ore from the waste. He had done away with the centre of the buddle, because the ore was collected in less space than the dead centre occupied. In ordinary buddles a small stream of water was with difficulty equally distributed over a large diameter, as when very finely divided ore was dealt with, only a small stream of water should be used: the water passed down on one side of the dead conical centre, so that one-third or one-fourth of the area of the buddle only was supplied with ore. That caused a waste of the ore from the surface of the buddle working unevenly; but by doing away with the centre, the water passed through the revolving tube of the buddle, spread equally over the surface, and was distributed at the centre with a velocity so great that it left the ore almost clean. The waste was carried off with hardly a particle of the tin, resulting from the greatly-reduced velocity of the water from the friction of the larger extent of surface the waste and water flowed over, after passing from the centre of this form of buddle. He could apply this process to the cleansing of gold, tin, copper, or lead, at a cost of about 4½*d.* per ton of stuff treated. This form of buddle was used in Australia for washing gold, and extensively in Cornwall for washing tin. Several had been sent to Norway, to separate copper ore from the matrix, and were much approved. They had also been at work at Esgarille, in North Wales, where 81 per cent. of slime lead had been obtained from the stuff treated. Another part of the buddle described in the Paper would be objectionable for general use. The arms were hollow and perforated with holes, through which jets of water were forced. This must cause a stream of water to run down the face of the buddle immediately in advance of the arm, and the finely-divided particles of ore must be washed away with the tailings. He used brushes with tufts of hair at intervals; these passing over the surface, broke the continuous flow of the water, and allowed the minutest particles of ore to be deposited near the centre. A plain piece of wood was sometimes used, which was dragged over the face of the buddle like a scraper: this also carried before it a stream of water with greater velocity than what flowed down the surface of the buddle, and washed the ore down into the tailings or waste. Therefore he was of opinion that a brush was the best. This would be applicable to very finely-divided gold, ores of tin, copper, or lead, but not to these ores in a rough state. In the former large quantities of water should be added to the ore. The diameter of the buddle should not exceed 12 feet or 15 feet, and no dead centre should be used. As far as the increased diameter of the buddle, referred to in the

Paper, went, he could confirm the statement of Mr. Warington Smyth, that they were now being made from 20 feet to 40 feet in diameter. His own buddles were made from 12 feet to 20 feet in diameter, regulated by the size of the particles of ore to be treated, and whether they had been crushed or stamped; it being a well-known fact that the science of separating ores from their gangue consisted in first classifying them.

Mr. T. Sopwith, jun., in reply upon the discussion, said, in speaking of the performances of his round buddle, that having resided for some time in Spain, it was difficult for him to know all that was passing in England, and the improvements that had been made. From the best information he could obtain, it was dressing about four times as much material as the 18-feet buddle in England was doing; as judged from works recognised as the best on the subject, viz., an article in 'Ure's Dictionary' on the Dressing of Ores, and another in 'Phillips' and Darlington's Mineralogical Processes:' both statements agreeing with his previous experience in England. He was not, therefore, to blame, though he much regretted, if he had understated, the recent performances of mining machinery in England. Mr. Taylor had remarked that the work at Linares was not so difficult as that in England. To that he could not agree. It was difficult to institute comparisons between the performances of washing machines in one locality as against the results obtained in another. He had, however, done all he could to premise the conditions of the material to be treated, first, by stating the quantity of material to be treated; secondly, in illustration of its hardness, providing and exhibiting specimens taken during actual working; and, thirdly, as to richness, fixing what might be called a fair and general percentage of lead contained in the vein stuff,—a standard equally applicable to English or Spanish lead mines. As to its being more difficult to dress than the generality of ores in England, with all deference to the great experience of Mr. Taylor, it might be questioned whether the ore in the North of England, which was considered to be the principal lead-producing district of England at the present time, and where the lead ores were associated principally with fluor spar, was not much easier of separation than those which he was treating in Spain, and of which the specimens exhibited were a fair sample. In reference to the crushing mills, exception had been taken to the springs for producing compression between the rollers, as not being equally efficient with the arrangement in use in England. His experience, however, was certainly in their favour, after having experimented on both arrangements. The tendency was, it would readily be understood, for the rollers to separate on the passage of the material. With the springs, as with the lever and weight used in England, varying degrees of compression could be given; but,

whereas, in the English system, this had to be effected by loading more weight into the boxes suspended at the end of the levers, in the case of the caoutchouc springs or buffers, a few turns of a regulating screw afforded the necessary compression, and their action at all times was steady. As to the rollers closing with a jerk, this was unavoidable in both systems. The recoil was, however, in his opinion, certainly greater in the English system than in the more compact arrangement described in the Paper. With regard to their wear, he had only used one set of springs in two years. When it was seen, by the particles being imperfectly crushed, that the springs were losing their power, they were easily changed. In place of changing the whole of the springs he had latterly taken out some of the caoutchouc discs and substituted for them pieces of wood, by which the elasticity of the buffer was reduced and the compression of the rollers proportionately increased. He was quite sure that a crushing mill with rollers 37 inches in diameter, made on the English system, would require more driving power than was used by him in Spain. For the whole of the machinery described on the lower dressing floors, crushing mill, Jacob's ladder, sizing trommels, hotching machines, round buddle and Brunton's cloth, were driven by a 10 H.P. steam-engine, consuming 7 cwt. of coal per day of nine hours. With respect to Mr. Warington Smyth's remarks on self-acting hotchers, he might say that during two years' residence in Germany, his attention was directed to that subject. He made choice of the self-acting hotcher, used in the works described, as that which was most adapted to the particular circumstances, and he believed to lead ores generally. Sufficient prominence was perhaps not given to this machine in the Paper. He would, therefore, briefly describe its action. (Plate 11.) The piston, in moving up and down, gave a quick down-stroke, during which the material to be hotched was raised, and a slow up-stroke whilst it subsided. The material, as it entered the hotcher, consisted of ore, chatts, and waste, mixed together. Every stroke of the piston raised the whole of the material, which was allowed to subside by its own weight. The accession of stuff caused a gradual advance of the material forward, and by the time the stuff had passed from *b* to *d*, perfect separation had taken place, and pure lead was left at the bottom and pure waste at the top. At each pulsation of the machine, the material found its exit through the apertures *d*, *e*. The intermediate stuff, consisting of chatts, lead and waste united, had to undergo further crushing. With respect to the subdivision of the material crushed into sizes, where the mine stuff presented small difficulty in the way of separation from the lead ore, being mixed with gangues of considerably less specific gravity, the number of sizes he had adopted would be found sufficient. If, however, the ore was united with blende or iron pyrites

to any considerable extent, or with any other gangue of almost equal specific gravity to the ore to be separated, then the subdivision would be effected into more sizes. He would be averse to treat by hotching, particles over 10 millimètres ($\frac{4}{10}$ths of an inch nearly) in diameter. As already described, the material hotched was stuff which would not pass through a plate perforated with holes of $1\frac{1}{2}$ millimètre, but which would pass through holes of 10 millimètres. This stuff was subdivided into four sizes. By increasing this subdivision to ten or twelve different sizes, the most refractory lead ores could, he observed, be dressed—in self-acting hotching machines. Captain Williams had evidently bestowed much careful attention in the improvement of the machine known as the round buddle. He coincided to some extent, though he could not but differ in the application of so small a centre. He had experienced considerable difficulty in condensing the information he had endeavoured to convey into the limits of one Paper—for of the several operations mentioned, crushing, hotching, treatment of sludge, and treatment of slimes, any one would afford subject for a more lengthened consideration than he had ventured to place before the Institution.

April 12, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

No. 1,277.—"The Maintenance and Renewal of Railway Rolling Stock."[1] By R. Price Williams, M. Inst. C.E.

From the moment the steam is first generated in a locomotive, or the first train mile has been run by a railway carriage or wagon, the dilapidation due to the destructive effects of wear and tear may be said to have begun, alike in the rolling stock and in the roadway that carries it.

The accumulated experience now possessed of the wear and tear of rolling stock, extending over a period of nearly forty years, enables the average life of each part of these structures to be as accurately determined as the average duration of human life under similar well-defined and recognized conditions.

It is probable that the average life values assigned to particular parts of the rolling stock, where indifferent materials and workmanship are met with, will be found as much below, as in other cases where first-rate materials and workmanship are combined they would be above, the standard adopted in the accompanying Tables. It is believed, however, that such exceptional experience will not materially affect their reliability when considered as average general results only.

In Tables A and B (Appendix, pages 158 to 187) the Author has dealt with an average goods engine and tender of approved make and design, in which the amount and cost of the labour are well proportioned to good and sound materials,—a class of engine adopted on one of the principal English railways.

In these Tables the average life, average gross and net cost, gross and scrap weight, and standard value of each portion of a locomotive engine and tender, are given in detail, from the break-block which requires to be renewed every six months, to the side-frame which will last thirty years. In this period of longest life, therefore, some parts will have to undergo renewals as many as sixty times, others thirty, twenty times, and so on.

[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

Engine Valuation.

Table A *a* is a condensed and classified summary of the aggregate lives and money values of the different portions which go to constitute an engine of the type given in Table A.

Table A *a*.

Locomotive Valuation.

Life in Train Miles.	Life in Years.	——	Net Cost.	Number of Renewals in period of longest Life.	Total Net Cost in period of longest Life (30 years).
	months.		£. decimal.		£. decimal.
10,000	6	India-rubber pipe	0·2625	60	15·7500
	years.				
80,000	4	Painting	8·2333	$7\frac{1}{2}$	61·7497
100,000	5	Brass tubes, steel ferrules, &c. .	162·2375	6	973·4250
120,000	6	Crank axles, moulds, &c. . .	51·2167	5	256·0835
140,000	7	Tires, pressure gauges, buffer-planks spindles, brass guards, washing-out plugs, &c. . .	156·8791	$4\frac{2}{7}$	672·3390
200,000	10	Boiler, axle-boxes and caps, brasses, brass valves and syphons, fire-box shell ends, tube-plate and back fire-box, copper recess plate, &c. . .	482·3812	3	1,447·1436
300,000	15	Motion cylinders, reversing catch-slide blocks, blast pipe, ash pan, outside and inside springs, spring links, spring pins, &c.	107·9549	2	215·9098
340,000	17	Lubricator, shackle, buffer-plank, chains	3·1834	$1\frac{13}{17}$	5·6177
400,000	20	Clack boxes, balls and clacks, feed pipes, smoke-box-door, &c.	17·4521	$1\frac{1}{2}$	26·1781
600,000	30	Two plain axles, 6 wheels, 6 outside cranks, 6 balance weights, slide-bar brackets, 8 slide-bars distance blocks, eccentric rods and straps, reversing arm, lever and bracket, reversing-rod shaft, quadrant and collar, 2 connecting rods and straps, bolts, framing, &c., &c. . .	523·0753	1	523·0753
			£1,512·8760		£4,197·2717

$$\frac{£4,197\cdot2717}{30} = £139\cdot9090 \text{ average cost of repairs per annum.}$$

$$\frac{£1,512\cdot8760}{139\cdot9090} = 10\cdot811 \text{ years' mean money life.}$$

The first series of extensive locomotive renewals occur, it will be seen, at intervals of five years, and cost during the period of longest life £973. These consist chiefly of the replacement of the brass tubes, steel ferrules, &c. The renewals of the crank axles follow in periods of six years, and cost £256. The great bulk however of the renewals take place at intervals of seven and ten years, and include amongst other things tires, boiler, axle-boxes, brasses, fire-box, copper recess plate, and other costly portions of the engine and tender, amounting altogether to £672 and £1,447 respectively.

The whole net cost of the renewals in thirty years amounts to £4,197. Dividing this sum by 30 (the period of longest life) there results £140 as the average annual cost per engine. Again, the total net cost of an engine being £1,513, it follows that this amount, divided by the average annual cost of renewals, gives 10·81 years as the average mean money life, so to speak; in other words, that period during which a sum will have been spent exactly representing the total net cost of an engine.

Table B *b*, Tender Valuation.

In Table B *b* is given a similarly condensed summary of the lives and money values of the different portions of the tender.

Table B *b*.

Tender Valuation.

Life in Train Miles.	Life in Years.	——	Net Cost.	Number of Renewals in period of longest Life.	Total Net Cost in period of longest Life.
	months.		£. decimal.		£. decimal.
10,000	6	Break blocks, rose packings, &c.	0·4250	60	25·5000
	years.				
60,000	3	Painting, tires, bolts, and nuts for ditto	39·9334	10	399·3340
100,000	5	Oak plank	1·3333	6	7·9998
200,000	10	Six axle-boxes and caps, 6 brasses and pins, &c., wood bottom and packing for tanks	8·0438	3	24·1314
300,000	15	Six springs, 6 buckles, 6 spring pins, trailing buffers, 2 buffer blocks, springs, &c. . . .	10·8812	2	21·7624
600,000	30	Three axles, 6 wheel centres, spring links frame plates, horn block stays, 104 bolts for frames angle irons, draw bolts, plates for buffer-planks coupling boxes, footplates, &c., erector's time, &c., break shaft and details, valve rods, &c., feed pipes, hand rails, &c., &c.	214·5764	1	214·5764
			£275·1931		£693·3040

$$\frac{£693\cdot3040}{30} = £23\cdot1101 \text{ average cost of repairs per annum.}$$

$$\frac{£275\cdot1931}{23\cdot1101} = 11\cdot908 \text{ years' mean money life.}$$

The total net cost of the tender is £275, and the total net cost of the repairs and renewals in the thirty years amounts to £693, equivalent to £23·11 per annum, and the mean life to 11·90 years.

Valuation of Engine and Tender combined.

From a reference to Table C it will be seen that the gross cost of an engine of the class referred to in Table A is £1,840·52, of which amount the materials represent four-fifths, and the value of the scrap one-fifth, or just the same as that of the labour. The gross cost of the tender is £340·74, the value of the materials being £256·68, or three-fourths of the whole sum, while the scrap value is only £65, or considerably less than the one-fourth which represents the labour.

TABLE C.—VALUATION OF ENGINE AND TENDER.
(Summary of Tables A *a* and B *b*.)

Mean Life in Train Miles.	Mean Life in Years.		Net Cost.	Total Net Cost in period of longest Life, viz., 30 years.
	years. dec.		£. decimal.	£. decimal.
216,280	10·814	Engine	1,512·8760	4,197·2717
238,160	11·908	Tender	275·1931	693·3040
			1,788·0691	4,890·5757

$\frac{£4,890·5757}{30}$ = £163·0192 average cost of repairs per annum.

$\frac{£1,788·0691}{163·0192}$ = 10·97 years' mean money life.

Gross cost of Engine:			
Materials	£1,509·0666		
Labour	331·4500		
		1,840·5166	
Gross cost of Tender:			
Materials	£256·6854		
Labour	84·0542		
		340·7396	
		2,181·2562	
Scrap value of Engine:			
Copper, Brass . . .	£157·7906		
Wrought and Cast Iron	169·8490		
	£327·6396		
Scrap value of Tender:			
Copper, Brass	£2·6875		
Wrought and Cast Iron .	62·8583		
	£65·5458		
Total Scrap value		393·1854	
Total Net Cost.		£ 1,788·0708	
Standard Net Value . . . £1,788·0708 × $\frac{2}{3}$ =		. . .	1,192·0472
Scrap value as above		. . .	393·1854
Total Standard running value . .		. . . £	1,585·2326
or 72·675 per cent. of the gross cost.			

The gross cost of the engine and tender combined is £2,181·25, and the total value of the scrap £393, leaving £1,788 as the total net cost of an engine and tender.

The total gross cost in the period of longest life is £4,891, and the average net cost per annum is £163, giving a mean average money life of 10·97 years.

The measure of life in rolling stock, as is well known, is represented by the number of miles run, 20,000[1] miles per engine per

[1] Mr. Ramsbottom is of opinion that 50 per cent. only of the engines should be in steam daily, and that 51 miles per day per engine in stock is all that can be calculated upon. This would give 18,615 as the average train mileage per engine per annum.

annum being considered a fair average performance in steam. The average mean money life, therefore, of all the parts of the engine and tender being 10·97 years, it follows that when it has run 220,000 miles, such an amount will have been spent in repairs and renewals (the same being practically identical) as would have entirely replaced it, credit being allowed for old material.

TABLE F.

VALUATION OF ENGINE AND TENDER.

Summary of Tables D *d* and E *e* (Appendix, pages 188 and 189).

Mean Life in Train Miles.	Mean Life in Years.		Net Cost.	Total Net Cost in period of longest Life, viz., 30 years.
			£. decimal.	£. decimal.
214,340	10·717	Engine	1,453·5531	4,068·9497
240,800	12·040	Tender	280·8854	700·0610
			1,734·4385	4,769·0107
$\frac{£4,769·0107}{30}$ = £158·9670 average cost of repairs per annum.				
$\frac{£1,734·4385}{158·9670}$ = 10·91 years' mean money life.				
Gross cost of Engine:				
Materials	£1,399·3125			
Labour	330·9500			
			1,730·2625	
Gross cost of Tender:				
Materials	£257·1229			
Labour	84·0542			
			341·1771	
			2,071·4396	
Scrap value of Engine:				
Copper, Brass, &c. . .	£157·7906			
Wrought and Cast Iron .	118·9187			
		£276·7093		
Scrap value of Tender:				
Copper, Brass, &c. . .	£ 2·6875			
Wrought and Cast Iron .	57·6042			
		£60·2917		
Total Scrap value . . .		£337·0010	337·0010	
Total Net Cost			1,734·4386	
Standard Net Value . . .	£1,734·4386 × $\frac{2}{3}$		. . .	1,156·2924
Add Scrap value			. . .	337·0010
Total Standard Running Value . .			. . . £	1,493·2934

or 72·09 per cent. of the Gross Cost.

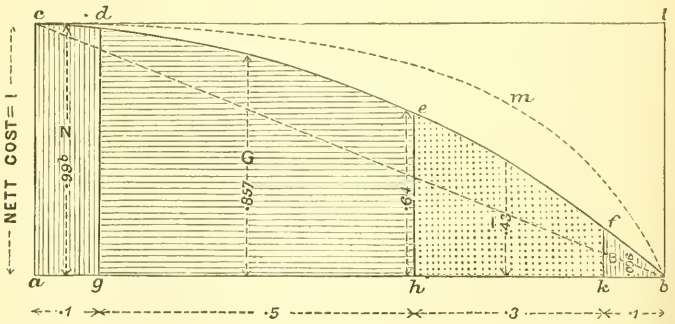
Table F similarly shows the valuation of a different standard type of engine and tender, in use on another line of railway. By referring to the details given in Tables D and E in the Appendix,[1] it will be seen that although the cost, and in some cases the life, of particular parts of this engine and tender differ from those given in Tables A and B, still the annual cost of the repairs and renewals, the mean money life, and the percentage of standard running value on the gross cost vary but slightly.

Inasmuch as the scrap value has always a fixed relation to the current prices of materials, it is clear that, in the consideration of the question of the cost of maintenance and the renewal of rolling stock, the valuation of scrap does not necessarily enter; no condition of dilapidation, either in rolling stock or in permanent way, being worse than the total net cost of its renewal.

For all practical purposes the locomotive and rolling stock required to carry on and to continue the traffic on a definite mileage of railway may be looked upon as permanent; so that when at length the most long-lived portions of either engine, carriage, or wagon have been consigned to the scrap heap, the life, or rather the identity of the structure, may be considered as preserved in its name or number plate.

Supposing the life of an engine to be divided into four periods,—called respectively 'New,' 'Good,' 'Indifferent,' and 'Bad,' it is evident that each of its component parts must necessarily go through all those stages of depreciation, *i.e.* from 'New' to 'Good,' from 'Good' to 'Indifferent,' and from 'Indifferent' to 'Bad,' until ultimately it is replaced by new material.

Fig. 1.



In the diagram Fig. 1 let the horizontal line *a b* represent the whole mean life of an engine, and let the vertical ordinates of the curve *c d e f b* represent its value at any time, starting with *a c*, the whole net cost, and going gradually down to nothing at *b*, the end

[1] These tables may be consulted in manuscript at the Institution.

of its life. The curve *c d e f b* will represent the rate of depreciation, and no doubt for each isolated engine, or any of its component parts, this curve would be an irregular line differing in each individual case. The greater the number of engines, however, the more nearly will the average of all these irregular lines approximate to some uniform curve, the precise character of which it would be impossible to ascertain without an immense amount of statistics of an inaccessible kind. The general nature of the curve however is at once discernible. It must be concave to the line *a b*, owing to the rate of dilapidations being always much slower at the starting point *a*, or at the beginning of an engine's life, than towards the end of its life at *b*, when its value will naturally decrease very rapidly. In order to arrive at the numerical values to be assigned to the coefficients of 'New,' 'Good,' 'Indifferent,' and 'Bad,' it is necessary to make some assumption as to the law which governs this rate of depreciation; and it is proposed to assume that the dilapidation increases as the square of the time, which condition is fulfilled by taking a parabolic curve *c d e f b*, whose vertex is at *c*, and axis is in the vertical line *a c*.

There is no doubt that, in the case of some of the parts of the engine, such as the side frames, boiler, and straight axles, the wear is tolerably uniform, and their curve of dilapidation would approximate to the straight line *c b*. On the other hand there are parts, such as the crank axles, motion, springs, brasses, and tires, which wear very rapidly at the end of their life, the curve for which would be more nearly represented by the dotted line *c m b*. The true mean of all these curves it would be impossible exactly to determine. The ordinary parabolic curve, which gives a dilapidation increasing as the square of the time, has been adopted as the nearest approximation, as from a reference to the diagram it will be seen, that it is a mean between the straight outline of uniform wear and the curved outline *c m b*, due to a much more rapid terminal wear varying as the cube of the time.

The next thing is to assign to the four stages 'New,' 'Good,' 'Indifferent,' and 'Bad' their respective periods in terms of the whole life of the engine. It is a well-known fact, and it becomes more apparent on an inspection of the diagram, that there is a small period at the commencement of the engine's life during which the rate of dilapidation is very slow indeed, and its amount almost inappreciable, and it is this small period which it is proposed to assign to the portion called 'New.' On the other hand there is a similarly small period at the other end of the life which may be characterised as 'Bad,' during which the rate of dilapidation is very quick indeed and the engine almost worthless.

It has already been shown, that the mean money life of all the parts of an engine amounts to 10·81 years. The Author has therefore assigned one-tenth of the whole life to each of these

periods of 'New' and 'Bad,' or, referring to the diagram, if $a\ b$ be taken as unity the intervals $a\ g$ and $k\ b$ will each be 0·1, leaving an intermediate space $g\ k = 0{\cdot}8$ as the sum of the two periods 'Good' and 'Indifferent;' and inasmuch as the results of all experience tend to assign a longer period to the portion called 'Good' than to that of 'Indifferent,' it is proposed to divide this intermediate space in the ratio of 5 to 3, as shown on the diagram.

The mean value of the engine during each of the four stages of its life is easily calculated from the nature of the curve assumed, and is as follows, in terms of the whole net cost:—

'New'	0·99333
'Good'	0·85733
'Indifferent' . . .	0·43000
'Bad'	0·09666

Normal Dilapidation.

It has also been shown, that the renewals of the various parts of the machinery occur at different periods, varying from six months to thirty years, and it therefore naturally follows, that in an engine of average condition parts of it may be expected to be found in every stage of dilapidation; in other words, that a certain and definite amount of dilapidation must always be present, quite irrespective of a thorough and efficient maintenance.

This normal dilapidation may be estimated as follows: It is obvious that the amount of 'New,' 'Good,' 'Indifferent,' and 'Bad,' in a stock of engines kept up to the average will be exactly proportional to the periods of time assigned for an engine passing through each of these stages, *i. e.*, as the numbers 1, 5, 3, and 1, respectively. There will consequently be 10 per cent. of 'New,' 50 per cent. of 'Good,' 30 per cent. of 'Indifferent,' and 10 per cent. of 'Bad,' and their respective values in terms of the net cost will be represented by the following numbers:—

'New' . . .	·1	× ·99333	= ·0993333
'Good' . . .	·5	× ·85733	= ·4286666
'Indifferent' . .	·3	× ·43000	= ·1290000
'Bad' . . .	·1	× ·09666	= ·0096666
			·6666666 = $\frac{2}{3}$rds.

The standard value of an engine, therefore, on the assumption of the depreciation increasing as the square of the time, is two-thirds, and the normal dilapidation one-third of the net cost, a result which is entirely independent of the arbitrary periods assigned to the four stages of dilapidation, and which might have been at once stated from a consideration of the fact that the whole area included between the curve $c\ d\ e\ f\ b$, and the lines $a\ c$, $a\ b$, is two-thirds of the area of the rectangle $a\ c\ l\ b$. This result differs slightly from the usually accepted theory, that the average

value of anything subject to wear and tear is half the net cost, which, of course, is based on the assumption that the rate of dilapidation is uniform, in which case the curve *c d e f b* would become the straight line *c b*.

It is submitted, however, that the assumption on which the present calculations are based, namely, that the dilapidations increase as the square of the time, and the results obtained therefrom, although not absolutely correct, give a nearer approximation to the truth than those obtained by the old method.

The result is to give a higher standard of efficiency, and to allow a less amount of normal dilapidation. The value of the ordinate *e h*, forming the division line between 'Good' and 'Indifferent,' is ·64 of the net cost, and coincides very closely with the standard value ·666. An engine, therefore, which is up to the standard value may be considered to be on the point of changing from the category of 'Good' into that of 'Indifferent.'

The above results are equally applicable to each or any of the component parts of an engine taken in detail, and their practical application will be shown in the sequel.

The diagram Fig. 2 is a representation of the successive renewals required by an engine and tender during thirty years, or the period of longest life, assuming that the lives of all the parts are precisely determinable, and, with some trifling exceptions, the same as those given in Tables A and B. The ordinates of the serrated curved line B, E, F, G, H, I, K, L give the net running value of the engine and tender at any given time, before and after each successive renewal, assuming that the dilapidation of each part increases as the square of the time. It will be seen that commencing at B with the entire net cost of a new engine and tender, viz., £1,788, the curve goes down by successive steps, until at the tenth year, notwithstanding repeated renewals of some of the minor parts, it sinks to the point E, corresponding on the scale to about £944. In this year the tubes would be renewed for the second time, and also the entire shell and copper plates of the firebox, making altogether an expenditure of £655, and the running value is therefore increased by that amount up to the point F. Between the tenth and the fifteenth years the curve again drops down, ultimately reaching the point H, at about the same level as E, in the tenth year, corresponding in value to £959.

The cylinders, tires, and tubes, are now renewed for the first, second, and third times respectively, making an entire expenditure in that year of £509, and again raising the curve of value by that amount from H to G.

From this point the curve falls at an increasing rate down to the point K, which it reaches at the twentieth year; the net running value of the engine, exclusive of scrap, being then only about

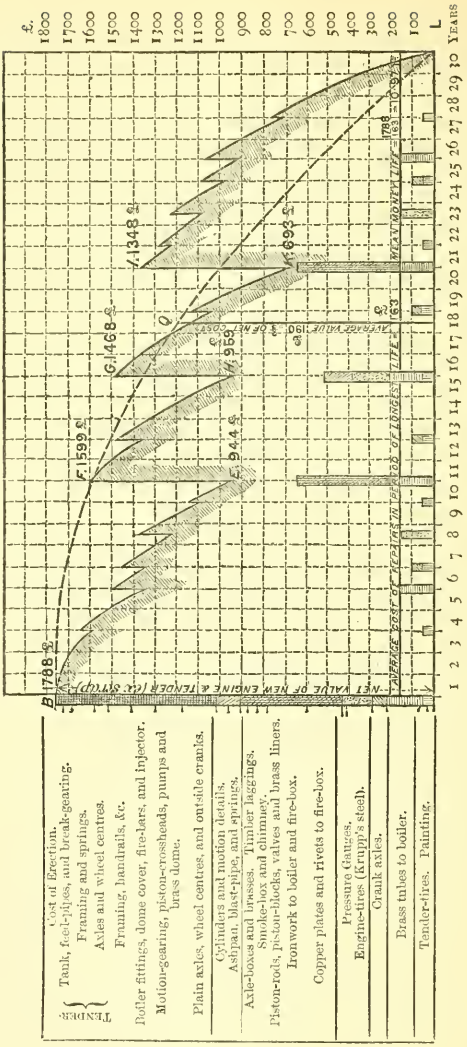


Fig. 2.

£693. The same large renewals would then be required as were done in the tenth year, raising the value to the point I, equivalent to about £1,350. Between the twentieth and the thirtieth years, the engine tires, crank axles, and tubes, would each be again renewed, but the curve of value rapidly falls, until the thirtieth year, at which time all the parts, including the longest lives, such as the framing, plain axles, &c., of the engine, and the greater part of the tender,

would be worn out, and the engine require to be replaced entirely. The dotted line B, F, Q, L is a parabolic curve, and is an exact average of the irregular curved line B, E, F, G, H, I, K, L just described. It may be called the average curve of depreciated value. It will be seen that at the point Q this curve coincides very nearly with the actual curve of depreciation, and at that point has come down to its average value, viz., £1,190, or two-thirds of the entire net cost, corresponding in point of time to about 17⅓ years, or ·577 of the ultimate life.

The dotted horizontal line R S, corresponding on the scale to £163·02, represents the average cost of renewals per annum during the whole thirty years, and the entire net cost, divided by this amount, gives about eleven years for the mean money life as before stated.

For the valuable data upon which Tables A and B are founded, the Author is indebted to Mr. F. W. Webb (Assoc. Inst. C.E.), late Chief Assistant to Mr. Ramsbottom (M. Inst. C.E.), and now of the firm of the Bolton Iron and Steel Company, of Bolton.

For the equally valuable and reliable data contained in Tables D and E, and for much other assistance, the Author is indebted to Mr. Charles Sacré (M. Inst. C.E.).

The Author, at the same time, desires to mention that the lives assigned to the different portions of the engine and tender in both the Tables have been verified by the independent experience of other engineers.

The average cost per engine of the locomotive stock belonging to the North Eastern Railway Company in 1864 was shown by Mr. Fletcher, in the statistics which accompanied the Paper[1] he presented to the Institution, to be £2,078. Taking 12½ per cent. of this amount, viz. £259·75, as representing the average annual cost of repairs and renewals, it follows that the average money life of the whole of the stock at that period was only eight years, or considerably below the standard given in the Author's Tables. This is no doubt accounted for by the fact, as stated by Mr. Harrison (V.P. Inst. C.E.), that a number of the North Eastern engines had to be rebuilt, not so much from their being worn out, as from the necessity of their being replaced by others of greater power and improved construction.

The dictum alluded to by Mr. Harrison during the discussion on Mr. Fletcher's Paper, "that if the average age of all the stock did not exceed one-half of the ultimate life of that stock, justice was done in maintaining it,"[2] was, in other words, saying, that the running value of any rolling stock should be taken at only half its cost, a method of valuation previously adverted to by the Author, as being based upon the assumption that the amount of dilapi-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 482. [2] *Ibid.*, p. 492.

dation varies directly as the time. It has already been shown, however, on the assumption that the dilapidation increases as the square of the time, that the actual period at which the ordinate of the curve attains its average value of two-thirds the net cost is a little more than half the ultimate life, viz., ·577, the effect being, in the case of the North Eastern railway, where the ultimate life is twenty-five years, to make the standard average age of the whole of the locomotive stock $14\frac{1}{2}$ instead of $12\frac{1}{2}$ years.

The mean actual age of the locomotive stock just referred to should not, however, be confounded with the "money-life," the first representing that proportion of the actual ultimate life beyond which the average age of the stock should not be permitted to go in order to maintain it in full efficiency; the latter merely being a coefficient employed in determining the actual cost of the renewals per annum in terms of the net cost.

Practical Application of Tables.

As a practical illustration of the mode of applying these Tables, for the purpose of estimating the running value of locomotive stock, let the following be assumed to be a report of the present condition of an engine and tender of the class given in Tables A and B:—

Table 1.

Valuation of Engine.

Total Net Cost.	Standard of Efficiency.		Actual Value.				
			Present Condition.	New.	Good.	Indifferent.	Bad.
£.	£			£.	£.	£.	£.
8·23	5·48	Painting . .	Good . .	..	7·05	..	..
4·51	3·00	Buffers . . .	Bad . . .	..	..	..	·44
162·24	108·16	Brass tubes .	Bad . . .	..	..	..	15·68
51·22	34·15	Crank axle . .	Indifferent .	..	..	22·02	..
6·63	4·42	Trailing ditto .	Bad . . .	..	..	..	0·64
6·63	4·42	Leading ditto .	Indifferent .	..	..	2·85	..
46·82	31·21	Trailing tires .	2 Bad . .	..	..	..	4·53
46·82	31·21	Leading ditto .	2 Indifferent	..	..	20·13	..
23·41	15·61	Driving ditto .	1 Good . .	..	20·07	..	..
23·41	15·61	Ditto do. .	1 New . .	23·25	..	..	..
9·97	6·65	Axle boxes . .	4 Good . .	..	8·55	..	..
4·98	3·32	Ditto do. .	2 Bad . .	..	..	..	·48
0·89	0·59	Brass valves .	Bad . . .	..	..	..	·09
0·36	0·24	Slide blocks .	1 set Bad .	..	..	..	·03
0·36	0·24	Ditto do. .	1 „ Indiffnt.	..	..	0·15	..
180·51	120·34	Fire box . .	Bad . . .	..	..	..	17·44
0·26	0·18	India-rubber hose-pipe	Bad . . .	..	..	..	·02
237·80	158·53	Boiler . . .	Good . .	..	203·87	..	..
697·82	465·22	Other portions of engine	Standard .	..	..	..	..
1,512·87	1,008·58			23·25	239·54	45·15	39·35

TABLE 2.

VALUATION OF TENDER.

Total Net Cost.	Standard of Efficiency.	——	Actual Value.				
			Present Condition.	New.	Good.	Indifferent.	Bad.
£.	£.			£.	£.	£.	£.
4·57	3·04	Painting . .	Bad . . .	..	..	..	·44
33·42	22·28	Tender frame .	Indifferent .	..	..	14·37	..
0·42	0·28	Break blocks .	Bad . . .	..	..	..	·04
9·74	6·49	2 Axles . . .	Good . .	..	8·35	..	..
4·87	3·24	1 Ditto . . .	Bad . . .	..	..	..	·47
2·08	1·39	2 Axle boxes .	New. . .	2·06	..	..	..
2·08	1·39	2 Ditto do. . .	Good . .	..	1·78	..	..
2·08	1·39	2 Ditto do. . .	Bad . . .	..	..	..	·20
·16	0·11	Buffer blocks .	Indifferent .	..	..	0·07	..
11·79	7·86	Trailing tires .	2 Bad . .	..	..	..	1·14
11·79	7·86	Leading ditto .	2 New . .	11·71	..	..	..
11·79	7·86	Ditto do. .	2 Indifferent	..	..	5·07	..
180·40	120·27	Other portions .	Standard .	..	..	..	..
275·19	183·46			13·77	10·13	19·51	2·29

TABLE 3.

SUMMARY OF RESULTS OF VALUATION.

Engine:		
Standard of efficiency		£1,008·58
Actual condition:		
New portions	£23·25	
Good ditto	239·54	
Indifferent ditto	45·15	
Bad ditto	39·35	
Standard ditto	465·22	
Total actual value . . .	£812·51	
		812·51
Total amount below standard . .		£196·07
Tender:		
Standard of efficiency		£183·46
Actual condition:		
New portions	£13·77	
Good ditto	10·13	
Indifferent ditto	19·51	
Bad ditto	2.29	
Standard ditto	120·27	
Total actual value . .	£165·97	
		165·97
Total amount below standard . .		£17·49

The standard of efficiency of an engine has been shown to be £1,008·58; the result therefore of the valuation in question is that

£196·07 will have to be spent upon it in order to restore it to that condition. In a similar way the standard of efficiency of a tender is found to be £183·46, and the condition of the tender here given is also below the standard to the extent of £17·49.[1]

The Author is of opinion, that similar Tables, adapted to the standard types of engines, carriages, wagons, and other portions of the rolling stock in use on different railways, might with advantage be adopted in the annual or bi-annual stock-takings. In this way alone will it be possible, he thinks, to arrive at that accurate and reliable knowledge of the actual condition of the rolling stock of a railway, so essential to its thoroughly efficient maintenance, and to afford that security as a permanent investment which railway property unfortunately stands so much in need of.

The results given in the Tables may be said to embody the workshop experience, so to speak, of the Engineers who have been named.

The Author has been enabled, by the kind assistance of the different railway companies, to verify the reliability of this experience, by a comparison with the actual working expenses during a long series of years. The results, which are given in the accompanying Tables and Diagrams, confirm in a remarkable way the soundness of the data upon which the Tables previously referred to have been based, more especially as regards the average money life of the engines. He regrets that, owing to the scanty information afforded in the earlier reports of some of the railways, he has not been able in every case to furnish the amount of the capital expended in rolling stock and other details, which it would have been useful to know. In several instances, however, this information has been furnished by the companies at considerable trouble.

In the case of the Great Northern railway, the actual amount of capital expended in the purchase and the renewal charges for the upholding of the locomotive and other rolling stock is given from the opening of the line down to the present time, a period of twenty years. Table T shows that the actual capital expenditure for locomotives on the Great Northern railway, in the twenty years referred to, has been £1,182,746; and that the total cost of repairs and renewals in the same period has amounted to £1,611,949, giving an average of £228 per engine per annum, and a consequent average money life of 10·52 years for the whole of the locomotive stock, or a little below the standard given in the preceding Table.

Tables 4 and 5 contain a summary of the average cost of repairs and renewals per annum, &c., on twelve of the principal English railways, given in detail in Tables G to S, and illustrated in the diagrams 6 to 17 (Plates 14, 15, and 16).

[1] In Tables 1ᴬ, 2ᴬ, and 3ᴬ in the Appendix will be found similar valuations, based on the assumption of uniform wear.

TABLES 4 AND 5 (COMBINED).

NAME OF RAILWAY.	Period of Years over which the Average is taken.	Average Number of Engines per Mile worked.	Average Number of Train Miles per Engine per Annum.	Running Expenses.			Repairs and Renewals.			Average Money Life in Years, assuming £2,400 as the average gross Cost of an Engine.
				Per Train Mile.	Per Standard Train Mile of 18,600 per Engine per Annum.	Per Engine per Annum.	Per Train Mile.	Per Standard Train Mile of 18,600 per Engine per Annum.	Per Engine per Annum.	
	No.	No.	No.	*d.*	*d.*	£.	*d.*	*d.*	£.	Years.
Great Eastern	18	0·45	18,188	5·6854	5·5594	430·94	2·9259	2·8875	221·81	10·819
Great Northern	20	0·71	18,343	4·8538	4·7867	369·00	2·9360	2·8954	228·00	10·526
Great Western	5	0·61	17,744	4·2265	4·0320	316·10	3·3651	3·2102	251·84	10·371[2]
Lancashire and Yorkshire	18	1·05[1]	17,480	4·8391	4·5477	350·52	2·6784	2·5171	195·00	12·308
London, Chatham, and Dover	6½	0·74	18,680	7·2749	7·3062	564·08	2·7351	2·7469	212·12	11·314
London, Brighton, and South Coast.	20	0·67	16,873	6·9972	6·3475	496·76	3·7993	3·4465	262·16	9·155
London and North Western	11	0·86[1]	16,095	4·5481	3·9356	336·42	3·4510	2·9862	228·72	10·4·3
London and South Western	23	0·45	21,146	5·0597	5·7523	447·52	3·1584	3·5907	272·40	8·811
Manchester, Sheffield, & Lincolnshire	17	0·61[1]	19,334	5·1731	5·3772	414·52	3·3099	3·4405	267·22	8·981
Midland	21	0·64	18,608	5·2473	5·2495	399·76	3·5644	3·5659	275·24	8·720
North London	8½	1·95	19,665	7·1663	7·5767	587·54	4·3920	4·6434	356·84	6·726
South Eastern	20½	0·62	17,110	5·6876	5·2323	403·80	3·1974	2·9414	226·44	10·601
Average	..	0·78	18,272	5·5632	5·4752	426·41	3·2927	3·2393	249·82	9·902

[1] Number at the present time.

[2] In the case of the Great Western, the mean cost of the broad and the narrow-gauge engines is taken at £2,612 per engine, calculated from data furnished by Mr. Armstrong.

Locomotive Expenses.

In Tables G to S inclusive, in the Appendix, are given in detail, for a period of more than twenty years, the cost of the principal items which constitute the locomotive running expenses of twelve of the principal English railways. The Author, wherever the information afforded would allow of it, has rearranged the various items of locomotive expenses, so as to adapt them to the form of account required by a recent Act of Parliament. A summary of these Tables is given in a condensed form in Table 6.

It is in the Author's opinion a matter of much regret, that a definite understanding has not been come to, as to what should constitute train mileage. On some lines it is still the practice to allow a certain amount of mileage while an engine is standing in steam; on other lines the running of extra and bank engines is treated as separate mileage, and the cost of the running expenses of marshalling the trains is charged to the traffic department. It is not, however, to this cause alone, that the remarkable difference in the cost per train mile of the locomotive expenses on the different railways is attributable, but rather to the varying ratio of the number of the engines per mile of line worked, and the consequent large difference in the average train mileage per engine on one line as compared with another.

It will be seen from Tables 4 and 5, that the number of engines per mile worked on the London and South Western has during the last twenty-three years only averaged 0·45, while the average number of train miles per engine per annum in the same period has been 21,146 miles, in some years amounting to 27,000 miles. The average cost of the whole of the locomotive expenses in the period referred to does not appear, from Table 6, to have been more than 8·50 pence per train mile. On the other hand, the average number of engines per mile worked on the whole of the other railways has been 0·78, and the average number of train miles per engine per annum has been 18,272 miles.[1] In the case of the London and North Western railway the average has only amounted to about 16,000 train miles, while the average cost of the whole of the locomotive expenses has been 9·32 pence per train mile.

If, however, the cost of the locomotive expenses per engine be taken as a basis of comparison, it will be found, from reference to Tables 4 and 5, that the average cost of the locomotive running expenses on the London and South Western, in a period of twenty-three years, has been very high, viz., £447 per engine per annum as against

[1] This mileage corresponds very nearly with Mr. Ramsbottom's estimated average. See *ante*, page 140.

TABLE 6.

DETAILS OF LOCOMOTIVE EXPENSES PER TRAIN MILE, AND PER ENGINE

NAME OF RAILWAY.	Number of Years' Average.	Salaries, Office Expenses, &c.		Running Expenses.								Total Running.		Repairs and Renewals.						Total of all Expenses.	
				Wages.		Coal.		Water.		Oil and Tallow.				Labour.		Materials.		Total.			
		Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.	Per Train Mile.	Per Engine per Annum.
		d. dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.	*d.* dec.	£. dec.
Great Eastern	18	0·1244	9·48	2·1303	161·44	2·7870	211·26	0·1660	12·58	0·6021	45·66	5·6854	430·94	Not given separately						2·9259	221·84	8·7357	662·26
Great Northern	20	0·6767	[1]52·80	1·8674	141·80	2·5569	193·80	0·1372	10·40	0·3077	24·20	4·8538	369·00	1·4001	108·60	1·5359	119·40	2·9360	228·00	8·4665	649·80
Great Western	5	[1]0·3337	[1]24·94	2·1128	157·78	1·6524	123·74	0·2620	19·66	0·1993	14·92	4·2265	316·10	Not given separately						3·3651	251·84	7·9253	592·88
Lancashire and Yorkshire	18	0·0768	5·56	2·1454	156·52	2·0922	110·20	0·1609	11·68	0·4406	32·12	4·8391	350·52	1·3526	98·40	1·3258	96·60	2·6784	195·00	7·5943	551·08
London, Chatham, and Dover	6½	[1]0·2922	[1]22·56	2·6754	207·26	3·7354	289·82	0·4006	30·88	0·4635	36·12	7·2749	564·08	Not given separately						2·7351	212·12	10·3022	798·76
London, Brighton, and South Coast	20	0·1603	11·34	2·2278	157·26	3·9414	280·80	Included in oil.	Included in oil.	[3]0·8170	[3]57·96	6·9972	496·76	Ditto ditto						3·7993	262·16	10·9568	770·26
London and North Western	11	[4]1·3175	[4]82·58	2·2120	147·62	1·9449	162·76	0·0606	3·78	0·3306	22·26	4·5481	336·42	Ditto ditto						3·4510	228·72	9·3166	649·74
London and South Western	23	0·2826	24·94	1·7968	160·10	2·6733	230·36	0·2894	27·70	0·4854	47·30	5·0597	447·52	1·5276	127·10	1·6308	145·30	3·1584	272·40	8·5007	744·86
Manchester, Sheffield, and Lincolnshire	17	0·7551	[1]61·78	2·2459	180·26	2·3741	189·58	Included in oil.	Included in oil.	[3]0·5531	[3]44·68	5·1731	414·52	1·6865	136·10	1·6234	131·12	3·3099	267·22	9·1937	739·88
Midland	21	0·2299	17·68	2·0897	161·68	2·5879	193·68	0·1750	13·56	0·3947	30·88	5·2473	399·76	1·5130	117·30	2·0514	157·94	3·5644	275·24	9·0416	692·68
North London	8½	0·5109	[1]41·14	3·0180	246·36	[2]3·7372	[2]307·14	0·4111	34·04	Included in coal.	Included in coal.	7·1663	587·54	Not given separately						4·3920	356·84	12·0692	985·52
South Eastern	20½	0·2398	17·00	2·1277	151·00	3·0800	218·60	0·2475	17·60	0·2325	16·60	5·6876	403·80	Ditto ditto						3·1974	226·40	9·1248	647·20

[1] Includes Miscellaneous Expenses. [2] Includes Oil and Tallow. [3] Includes Water. [4] Includes working Cromford and High Peak Railway, and Miscellaneous Expenses.

£336 on the London and North Western, while the average cost of the repairs and renewals per engine has amounted to £272 per annum, giving only an 8·8 years' money life as compared with £229 and a 10·5 years' life on the London and North Western.

It is obvious that it would be as unfair to take the cost of the running expenses per engine as a basis for comparison in the one case, as it would be to take the cost per train mile in the other.

In the opinion of the Author, the only fair mode of instituting a comparison, between the locomotive expenses of one line with another differently circumstanced as to the nature and extent of its traffic, is by adopting a certain standard or nominal train mileage per engine, as shown in Tables 4 and 5.

The value of a series of reliable results, showing the comparative working expenses on different railways, cannot, in his opinion, be too much dwelt upon, and he hopes that in bringing this subject forward it may tend to further the desired object.

The exceptionally large cost per train mile of coal and coke in the case of the London and Brighton railway, as compared with similar charges on the other railways, will not fail to be noticed, and requires some explanation from the locomotive engineer of that line.

It will also be observed that the discontinuance of the use of coke as fuel for the engines has led in all cases, but more especially on the London and North Western, to a considerable reduction in the cost of that large item in locomotive expenditure. With these exceptions the cost per train mile of the other items of the running expenses generally preserve a very uniform outline. The same remark applies to the cost per train mile of the repairs and renewals of late years, indications which it is thought go a good way to show, that the rolling stock is being more adequately maintained, and that fair average results as regards running expenses have at last been arrived at.

The question of the economy, or otherwise, of working a long mileage of line with a small number of engines, but with a train mileage per engine largely in excess of the average, is one deserving of attention. It is evident that, whatever the special circumstances and conditions of a particular railway may be, there must be some point where the maximum of work done and the efficiency of maintenance can be realised at a minimum cost and with a minimum number of engines; and could it be shown, in the case of the London and South Western, that in a period extending over a considerable number of years, notwithstanding the comparative short life of their locomotive stock, the average annual cost of the whole of the locomotive charges per engine has been less than on other railways, it would go a long way to establish the soundness of the policy of obtaining the greatest mileage out of an engine, regardless

of its effect in shortening the duration of its life. Supposing, for instance, a given mileage and a given amount of traffic to be worked in one case by fifty engines, or a third less than the number previously employed, it is manifest that if the extra dilapidations caused by the hard running does not cost as much as the interest upon the capital that would have to be expended in the purchase of twenty-five engines, it is cheaper to work with the smaller number of engines.

Repairs and Renewals of Carriages and Wagons.

Tables V, W, X, and the diagrams Figs. 18, 19, 20 (Plate 16), show the cost of the repairs and renewals of carriages; and Tables V^1, W^1, X^1, and the diagrams Figs. 21, 22, 23 (Plate 16), the cost of the repairs and renewals of wagons on the Great Northern, the Manchester, Sheffield, and Lincolnshire, and the North London railways during a period of years.

In the accounts of the other railway companies the cost of the repairs and renewals of carriages and wagons is not shown separately. The Author has therefore been unable to acquire any experience in regard to these important items of railway expenditure on those railways. The absence of such detailed information during past years is much to be regretted, since the data to be derived from the "repairs and renewals" expenditure upon a large rolling stock, such, for instance, as that of the London and North Western railway, during a long period of years, would be exceedingly valuable.

It is thought, however, that in the accompanying Tables sufficient information is given to enable the average money-life of both carriages and wagons to be approximately determined, more especially since the average cost of the maintenance and renewal per vehicle is found to correspond very closely with the results given in Mr. Fletcher's Paper, already alluded to.[1]

Carriage Repairs and Renewals.

From a reference to the tabular statement given in Mr. Fletcher's Paper, it appears that the average cost of repairs and renewals per carriage on the North Eastern railway, during a period of twelve years, was £22. 0*s*. 9*d*., or 11·26 per cent. on the total cost, equivalent to a money-life of 8·9 years, the mean actual age of the whole stock, taken at half its ultimate life, being 9·75 years.

The average annual cost of carriage repairs and renewals on the Great Northern railway, during a period of twenty years, is almost

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., page 461.

exactly the same, viz., £22·24, as will be seen from a reference to the following tabular statement:—

TABLE 7.

NAME OF RAILWAY.	Period of Years.	Number of Carriages per Mile worked.	Average Cost per Vehicle per Annum.	Mean Money Life.	Average Cost per Train Mile.	Average Cost per Passenger Train Mile.
			£. dec.	years.	d. dec.	d. dec.
Great Northern . . .	20	1·73	22·24	9·036	0·6939	1·5960
Manchester, Sheffield, and Lincolnshire . . .	17	1·14*	20·71	8·547	0·6805	1·3725
North London	9	9·48	35·26	7·935	2·0913	2·8283†

* Average of three last half-years. † Average of five last half-years.

WAGON REPAIRS AND RENEWALS.

The average annual cost of the repairs and renewals of wagons per vehicle on the three railways just referred to, during a period of years, was as follows:—

TABLE 8.

NAME OF RAILWAY.	Period of Years.	Number of Wagons per Mile worked.	Average Cost per Vehicle per Annum.	Mean Money Life.	Average Cost per Train Mile.	Average Cost per Goods Train Mile.
			£. dec.	years.	d. dec.	d. dec.
Great Northern . . .	20	17·19	4·94	14·876	1·4522	2·5978
Manchester, Sheffield, and Lincolnshire . . .	17	16·00*	4·18	17·400	1·7036	3·4173
North London . . .	9	16·70	4·83	16·903	0·5181	2·9322†

* Average of three last half-years. † Average of five last half-years.

The average cost of 17,429 wagons on the North Eastern railway appears to have been £73. 14*s.* 8*d.* per wagon, and the average annual cost of their maintenance and renewal, during a period of twelve years, £4. 8*s.* 4*d.* per vehicle, being 6·39 per cent. of the total cost, and equivalent to a money-life of 15·65 years, the actual mean age of the whole stock at that time being 10·31 years.

The cost of the repairs and renewals of both carriages and wagons is usually estimated at per train mile. The absurdity of adopting any such basis for comparing the relative cost of these charges on various railways, whose goods and passenger traffic differ so essentially, is sufficiently obvious, and is strikingly exemplified in the

diagrams, which show respectively the cost per vehicle per annum, the cost per train mile, and the cost per goods or passenger train mile, as the case may be.

The Author would observe, in conclusion, that although slight variations in the types or classes of engines, carriages, and wagons on a particular railway do not materially affect the average life values of the whole of a rolling stock, still the fewer the types of the engines and the greater the interchangeableness of the parts, and the more durable the character of the material, the nearer will the actual results in practice approach the estimated life given in these Tables.

In bringing this subject under the notice of the Institution, the Author hopes that his investigations, imperfect as they are, may lead to the acquirement of that information, to use Mr. Harrison's words, "which might govern Boards of Directors, and superintendents in advising them, upon one of the most important items of outlay which they must incur in maintaining the stock in a full state of efficiency."[1]

The communication is illustrated by numerous Tables, some of which are given either in the body of the Paper or in the Appendix, and by an extensive series of Diagrams, corresponding to the Tables, all of which have been reproduced, on a small scale, in Plates 13, 14, 15, 16, and 17, and in the wood engravings, Figs. 1, 2, 3, and 4.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 494.

APPENDIX.

Tables:

A, B	Valuation of Engine and Tender based on Mr. Webb's data.
D, E[1]	Valuation of Engine and Tender based on Mr. Sacré's data.
D*d*, E*e*, ...	Summaries of Tables D and E.
G to S[1]	Details of Locomotive Expenditure, showing the average cost per Engine and per Train mile on twelve of the principal English railways, viz.: The Great Eastern. The Great Northern. The Great Western. The Lancashire and Yorkshire. The London, Chatham, and Dover. The London, Brighton, and South Coast. The London and North Western. The London and South Western. The Manchester, Sheffield, and Lincolnshire. The Midland. The North London, and The South Eastern.
T, U[1].	Tables showing the Capital and Revenue, Expenditure on Locomotive construction and maintenance on the Great Northern and Midland railways for the past twenty and fourteen years respectively.
V, W, X[1]. . . . V[1], W[1], X[1] . . .	Tables showing the Cost, Repair, and Renewal of Carriages and Wagons on the Great Northern, the Manchester, Sheffield, and Lincolnshire, and the North London railways.

[1] Tables D, E, G to S, T, U, V, W, X, and V[1], W[1], X[1], may be consulted in manuscript at the Institution. They are represented graphically in Plates 14, 15, 16, and 17.

Diagrams:

Fig. 5	Representing Standard Types of Engines (Plate 13).
„ 6 to 17 inclusive	Illustrating Tables G to S (Plates 14, 15, and 16).
„ 18 to 23 „ .	Illustrating Tables V, W, X, and V[1], W[1], X[1] (Plate 17).

TABLE A.[1]—ENGINE VALUATION (based upon Mr. WEBB's data).

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.	Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.	years.										
MOTION CYLINDERS, ETC.																	
2 slide valves	1 0 26	.. ..	6 18 0	5 3 6	0 3 4	5·3417	15	3·5611	5·3060	4·5796	2·2969	0·5164	2·6708	5·0961	3·4036	1·3140	0·2456
2 valve spindles	.. ..	1 1 8	1 3 9	0 16 3	2 0 11	2·8583	15	1·9056	2·8392	2·4505	1·2291	0·2763	1·4292	2·7269	1·8694	0·7031	0·1314
1 set of gland bushes	0 3 8	.. ..	4 12 0	3 9 0	0 8 2	3·8583	15	2·5722	3·8326	3·3079	1·6591	0·3730	1·9291	3·6808	2·5234	0·9491	0·1774
1 set of studs and washers	.. ..	0 3 20	0 9 3	0 4 9	1 11 3	1·8000	15	1·2000	1·7880	1·5432	0·7740	0·1740	0·9000	1·7172	1·1772	0·4427	0·0827
1 pair of 16 in. cylinders and covers	.. ..	33 2 18	28 12 3	18 11 3	15 0 10	33·6042	15	22·4028	33·3802	28·8100	14·4498	3·2484	16·8021	32·0591	21·9778	8·2659	1·5451
2 cylinder cover handles	.. ..	0 0 4	0 0 4	0 0 2	0 0 9	0·0458	15	0·0305	0·0455	0·0393	0·0197	0·0044	0·0229	0·0437	0·0299	0·0113	0·0021
						47·5083	..	31·6722	47·1915	40·7305	20·4286	4·5925	23·7541	45·3238	31·0713	11·6861	2·1843
1 crank axle mould	.. ..	23 1 0	55 16 0	48 16 6	2 7 10	51·2167	6	34·1445	50·8753	43·9097	22·0232	4·9509	25·6084	48·8618	33·4967	12·5983	2·3549
2 plain axles	.. ..	17 3 1	17 15 2	12 8 8	0 16 8	13·2667	30	8·8445	13·1783	11·3740	5·7047	1·2824	6·6333	12·6567	8·6767	3·2633	0·6160
6 wheels 5 feet diameter	.. ..	61 3 20	99 1 9	80 11 3	6 1 0	86·6125	30	57·7417	86·0352	74·2558	37·2434	8·3726	43·3063	82·6301	56·6463	21·3049	3·9824
30 keys for ditto	.. ..	0 3 0	0 7 6	0 3 0	0 10 0	0·6500	30	0·4334	0·6457	0·5573	0·2795	0·0628	0·3250	0·6201	0·4251	0·1600	0·0299
6 outside cranks	.. ..	12 0 12	24 4 3	20 12 3	3 13 0	24·2625	30	16·1750	24·1008	20·8010	10·4329	2·3454	12·1312	23·1469	15·8682	5·9681	1·1156
6 balance weights Plates, rivets, &c.	.. ..	4 3 26	1 15 3	0 6 9	1 16 0	2·1375	30	1·4250	2·1231	1·8326	0·9190	0·2067	1·0688	2·0392	1·3980	0·5258	0·0983
						126·9292	..	84·6196	126·0831	108·8207	54·5795	12·2699	63·4646	121·0930	83·0143	31·2221	5·8362
6 tires, 5 feet (Krupp steel) 30 bolts	.. ..	42 3 10	149 10 2	136 13 8	3 15 9	140·4708	7	93·6472	139·5343	120·4303	60·4024	13·5788	70·2354	134·0119	91·8707	34·5530	6·4588
6 axle-boxes and caps	.. ..	12 1 22	4 19 7	1 6 1	0 8 10	1·7458	10	1·1639	1·7342	1·4967	0·7507	0·1688	0·8729	1·6655	1·1418	0·4294	0·0803
6 ditto brasses	2 1 10	.. ..	13 2 0	9 16 6	3 6 10	13·1667	10	8·7777	13·0789	11·2883	5·6617	1·2728	6·5833	12·5613	8·6113	3·2387	0·6054
12 pins for ditto	.. ..	0 0 18	0 1 7	0 0 8	0 0 3	0·0458	10	0·0305	0·0455	0·0393	0·0197	0·0044	0·0229	0·0437	0·0300	0·0113	0·0021
12 syphon pipes	.. ..	.. ..	0 2 6	0 2 6	0 0 10	0·1667	10	0·1111	0·1656	0·1429	0·0717	0·0161	0·0834	0·1590	0·1090	0·0410	0·0077
2 inside axle-boxes	2 3 27	.. ..	16 15 0	12 11 3	1 3 9	13·7500	10	9·1667	13·6583	11·7883	5·9125	1·3292	6·8750	13·1178	8·9928	3·3822	0·6322
2 inside caps	.. ..	1 0 8	0 8 7	0 2 7	0 0 3	0·1417	10	0·0945	0·1408	0·1215	0·0609	0·0137	0·0708	0·1352	0·0927	0·0349	0·0065
2 pins for ditto	.. ..	0 0 6	0 0 6	0 0 2	.. ..	0·0083	10	0·0055	0·0082	0·0071	0·0036	0·0008	0·0042	0·0079	0·0054	0·0020	0·0004
						29·0250	..	19·3499	28·8315	24·8841	12·4808	2·8058	14·5125	27·6904	18·9830	7·1395	1·3346
4 slide bar brackets	.. ..	0 1 18	0 6 7	0 5 1	0 15 11	1·0500	30	0·7000	1·0430	0·9002	0·4515	0·1015	0·5250	0·0017	0·6867	0·2583	0·0483
8 slide bars	.. ..	4 2 18	7 18 6	6 11 6	1 13 3	8·2373	30	5·4916	8·1826	7·0622	3·5421	0·7963	4·1188	7·8587	5·3875	2·0263	0·3788
Bolts and nuts	.. ..	0 1 0	0 2 6	0 1 0	0 6 10	0·3917	30	0·2611	0·3891	0·3358	0·1684	0·0379	0·1958	0·3737	0·2562	0·0963	0·0180
Distance blocks	.. ..	0 0 10	0 0 6	0 0 2	0 3 0	0·1583	30	0·1056	0·1572	0·1357	0·0681	0·0153	0·0792	0·1510	0·1035	0·0389	0·0073
2 motion links	.. ..	0 3 24	0 17 4	0 12 10	1 8 4	2·0583	30	1·3722	2·0445	1·7646	0·8851	0·1990	1·0291	1·9637	1·3462	0·5063	0·0946
4 lifting links	.. ..	0 2 20	0 12 3	0 9 3	1 17 1	2·3167	30	1·5445	2·3012	1·9862	0·9962	0·2240	1·1584	2·2102	1·5152	0·5699	0·1065
1 lifting lever	.. ..	0 3 17	0 16 3	0 11 9	1 7 10	1·9792	30	1·3195	1·9660	1·6968	0·8510	0·1913	0·9896	1·8882	1·2944	0·4868	0·0910
2 valve spindle slides	.. ..	1 2 20	1 10 3	1 1 3	2 9 1	3·5104	30	2·3444	3·4932	3·0149	1·5122	0·3399	1·7583	3·3550	2·3000	0·8650	0·1617
						19·7083	..	13·1389	19·5768	16·8964	8·8746	1·9052	9·8542	18·8022	12·8897	4·8478	0·9062
Carried forward	7 1 15	222 3 20	437 19 7	361 9 7	53 7 7	414·8583	..	276·5723	412·0925	355·6717	178·7891	40·1031	207·4292	395·7831	271·3257	102·0468	19·0750

[1] A summary of this Table is given on page 186.

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	7 1 15	222 3 20	437 19 7	361 9 7	53 7 7	414·8583
2 valve spindle brackets .	1 1 6	.. ..	7 6 0	5 9 6	.. ..	5·4750
Patent metal	0 1 0	.. ..	1 8 9	1 1 9	0 0 6	1·1125
						6·5875
2 syphons	.. ..	.. ..	0 2 1	0 2 1	0 13 0	0·7542
4 eccentric rods	.. ..	2 0 0	1 16 0	1 4 0	2 2 6	3·3250
4 eccentric straps . . .	.. ..	5 1 24	12 5 11	10 14 5	7 10 8	18·2542
						22·3334
4 brass liners	2 0 9	.. ..	11 13 0	8 14 9	1 1 2	9·7958
Patent metal	0 1 20	.. ..	2 9 3	1 17 3	0 4 6	2·0875
						11·8833
Bolts and nuts for straps .	.. ..	0 1 12	0 3 7	0 2 1	0 9 5	0·5750
4 eccentric sheaves . . .	.. ..	4 2 0	1 7 0	0 9 0	2 3 6	2·6250
8 studs and cotters for ditto	.. ..	0 1 4	0 2 10	0 1 4	0 3 2	0·2250
						3·4250
1 reversing catch and bolt .	.. ..	0 0 6½	0 1 0	0 0 8	0 3 6	0·2083
1 spring	0 0 1	.. ..	0 0 3	0 0 2¼	0 1 0	0·0594
						0·2677
1 reversing arm	.. ..	0 1 18	0 6 7	0 5 1	0 15 2	1·0125
1 reversing lever bracket .	.. ..	0 0 12½	0 2 0	0 1 5	0 5 2	0·3292
						1·3417
1 reversing brass guide . .	0 0 3½	.. ..	0 3 6	0 2 7½	0 1 0	0·1812
1 reversing rod (complete) .	.. ..	1 2 10	1 5 5	0 16 5	3 2 1	3·9250
1 reversing shaft and collar	.. ..	1 2 7	1 5 0	0 16 0	0 17 10	1·6917
1 quadrant	.. ..	0 3 26	0 15 9	0 11 3	0 14 11	1·3083
						6·9250
2 pedestals	0 3 6	.. ..	4 10 0	3 7 6	0 9 1	3·8292
1 bracket	0 0 18	.. ..	0 18 0	0 13 6	0 2 8	0·8083
						4·6375
Carried forward . .	12 1 22½	240 1 0	486 1 6	398 0 4¾	74 8 5	472·4106

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.										
..	276·5723	412·0925	355·6717	178·7891	40·1031	207·4292	395·7831	271·3257	102·0468	19·0750
10	3·6499	5·4385	4·6939	2·3542	0·5292	2·7375	5·2233	3·5808	1·3467	0·2517
10	0·7417	1·1052	0·9538	0·4784	0·1075	0·5562	1·0613	0·7276	0·2736	0·0511
..	4·3916	6·5437	5·6477	2·8326	0·6367	3·2937	6·2846	4·3084	1·6203	0·3028
30	0·5028	0·7492	0·6466	0·3243	0·0729	0·3771	0·7195	0·4933	0·1855	0·0347
30	2·2167	3·3029	2·8506	1·4297	0·3214	1·6625	3·1721	2·1746	0·8179	0·1529
30	12·1694	18·1326	15·6499	7·8493	1·7646	9·1271	17·4149	11·9386	4·4902	0·8394
..	14·8889	22·1847	19·1471	9·6033	2·1589	11·1667	21·3065	14·6065	5·4936	1·0270
10	6·5305	9·7304	8·3983	4·2122	0·9469	4·8979	9·3454	6·4066	2·4096	0·4504
10	1·3917	2·0735	1·7896	0·8977	0·2018	1·0437	1·9915	1·3653	0·5135	0·0960
..	7·9222	11·8039	10·1879	5·1099	1·1487	5·9416	11·3369	7·7719	2·9231	0·5464
30	0·3833	0·5712	0·4930	0·2472	0·0556	0·2875	0·5486	0·3761	0·1414	0·0264
30	1·7500	2·6075	2·2505	1·1288	0·2537	1·3125	2·5043	1·7168	0·6457	0·1207
30	0·1500	0·2235	0·1929	0·0967	0·0217	0·1125	0·2147	0·1472	0·0553	0·0103
..	2·2833	3·4020	2·9364	1·4727	0·3310	1·7125	3·2676	2·2401	0·8424	0·1574
15	0·1389	0·2069	0·1786	0·0896	0·0202	0·1041	0·1987	0·1362	0·0512	0·0096
15	0·0396	0·0590	0·0509	0·0255	0·0057	0·0297	00·567	0·0388	0·0146	0·0027
..	0·1785	0·2659	0·2295	0·1151	0·0259	0·1338	0·2554	0·1750	0·0658	0·0123
30	0·6750	1·0057	0·8680	0·4354	0·0979	0·5063	0·9659	0·6622	0·2490	0·0465
30	0·2195	0·3270	0·2823	0·1416	0·0319	0·1646	0·3141	0·2153	0·0810	0·0151
..	0·8945	1·3327	1·1503	0·5770	0·1298	0·6709	1·2800	0·8775	0·3300	0·0616
15	0·1208	0·1800	0·1554	0·0779	0·0175	0·0906	0·1729	0·1185	0·0446	0·0083
30	2·6167	3·8988	3·3650	1·6878	0·3794	1·9625	3·7445	2·5670	0·9655	0·1804
30	1·1278	1·6804	1·4503	0·7274	0·1635	0·8459	1·6139	1·1064	0·4161	0·0778
30	0·8722	1·2996	1·1216	0·5626	0·1265	0·6541	1·2481	0·8557	0·3218	0·0602
..	4·6167	6·8788	5·9369	2·9778	0·6694	3·4625	6·6065	4·5291	1·7034	0·3184
15	2·5528	3·8036	3·2829	1·6466	0·3701	1·9146	3·6531	2·5044	0·9419	0·1761
15	0·5389	0·8029	0·6930	0·3476	0·0781	0·4042	0·7711	0·5286	0·1988	0·0372
..	3·0917	4·6065	3·9759	1·9942	0·4482	2·3188	4·4242	3·0330	1·1407	0·2133
..	314·9605	469·2907	405·0388	203·5496	45·6692	236·2203	450·7177	308·9857	116·2107	21·7225

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	12 1 22½	240 1 0	486 1 6	398 0 4¾	74 8 5	472·4406
8 studs, washers, and nuts .	.. ..	0 0 16	0 1 5	0 0 7	0 4 2	0·2375
4 angle irons	.. ..	0 1 2	0 2 8	0 1 2	0 5 2	0·3167
Rivets	.. ..	0 0 3	0 0 7	0 0 5	0 6 4	0·3375
14 pins and washers . . .	.. ..	0 1 2½	0 4 10	0 3 4	0 10 0	0·6667
1 balance weight . . .	.. ..	1 0 21	0 7 2	0 3 2	0 1 0	0·2083
14 split pins	.. ..	0 0 5	0 0 10	0 0 7	0 1 4	0·0958
Hardening motion . . .	.. ..	.. ..	1 9 9	1 9 9	0 17 0	2·3375
Lapping out holes . . .	.. ..	.. ..	.. ..	.. ..	0 12 4	0·6167
3 tumbler slips	.. ..	0 1 7	0 3 2	0 1 8	0 9 8	0·5667
6 bolts and nuts	.. ..	0 0 3	0 0 3	0 0 1	0 2 1	0·1083
Snudries, drilling and fitting splash plates (complete) .	.. ..	0 3 13	0 11 8	0 7 2	13 12 0	13·9583
						19·2125
2 connecting rods . . .	.. ..	4 3 9	6 0 9	4 12 3	1 10 2	6·1208
Straps	.. ..	1 2 23	2 2 8	1 13 8	2 19 8	4·6667
Ditto	.. ..	1 0 6	1 6 4	1 0 4	1 9 8	2·5000
4 long bolts	.. ..	0 1 14	0 6 9	0 5 3	0 11 7	0·8417
						14·1292
4 gibs and 4 cotters . . .	.. ..	0 1 12	0 6 5	0 4 11	0 9 10	0·7375
2 glut pieces	.. ..	0 0 11	0 1 0	0 0 5	0 1 10	0·1125
2 pair large brasses . . .	1 0 7	.. ..	5 19 0	4 9 3	0 7 0	4·8125
2 pair small ditto . . .	0 1 2	.. ..	1 10 0	1 2 6	0 2 9	1·2625
2 syphons	.. ..	0 0 2	0 0 1	0 0 0½	0 1 1	0·0563
6 sets of screws	0 0 1½	.. ..	0 0 4	0 0 3½	4 10 10	4·5552
Patent metal	0 0 16	.. ..	0 16 4	0 12 4	0 0 10	0·6583
Copper recess plates . . .	0 0 26	.. ..	1 4 5	0 17 11	0 7 0	1·2458
						13·4406
4 coupling-rod ends . . .	.. ..	2 1 8	2 18 0	2 4 6	2 7 0	4·5750
2 ditto with single joints .	.. ..	1 2 24	2 2 11	1 13 11	0 4 9	1·9333
2 ditto double ditto . . .	.. ..	0 3 12	1 1 5	0 16 11	5 15 2	6·6042
2 joint-pins, nuts, and washers	.. ..	0 0 18	0 2 11	0 1 11½	0 7 1	0·4521
						13·5646
6 cotters	.. ..	0 0 23	0 2 1	0 0 10½	0 2 6	0·1687
6 glut pieces	.. ..	0 0 18	0 1 7	0 0 7½	0 2 8	0·1646
						0·3333
Carried forward . .	14 0 18¾	257 1 0½	515 6 10	420 6 3	113 0 11	533·3583

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	314·9605	469·2907	405·0388	203·5496	45·6693	236·2203	450·7177	308·9857	116·2107	21·7225
..										
30	0·1583	0·2359	0·2036	0·1021	0·0229	0·1187	0·2266	0·1553	0·0584	0·0109
15	0·2111	0·3146	0·2715	0·1362	0·0306	0·1584	0·3021	0·2071	0·0779	0·0146
15	0·2250	0·3352	0·2893	0·1451	0·0326	0·1687	0·3221	0·2207	0·0830	0·0155
15	0·4445	0·6623	0·5716	0·2867	0·0644	0·3334	0·6360	0·4360	0·1640	0·0306
15	0·1389	0·2069	0·1786	0·0895	0·0201	0·1041	0·1987	0·1362	0·0512	0·0096
15	0·0639	0·0952	0·0822	0·0412	0·0093	0·0479	0·0914	0·0627	0·0236	0·0044
15	1·5583	2·3219	2·0040	1·0052	0·2260	1·1688	2·2302	1·5288	0·5750	0·1075
15	0·4111	0·6126	0·5287	0·2652	0·0596	0·3083	0·5883	0·4033	0·1517	0·0284
15	0·3778	0·5629	0·4859	0·2437	0·0549	0·2834	0·5406	0·3706	0·1394	0·0261
15	0·0722	0·1077	0·0929	0·0465	0·0105	0·0541	0·1031	0·0708	0·0266	0·0050
15	9·3055	13·8653	11·9670	6·0020	1·3494	6·9792	13·3165	9·1290	3·4335	0·6418
..	12·8083	19·0846	16·4717	8·2613	1·8574	9·6063	18·3290	12·5652	4·7259	0·8835
30	4·0805	6·0799	5·2476	2·6319	0·5916	3·0604	5·8394	4·0031	1·5056	0·2814
30	3·1111	4·6355	4·0008	2·0066	0·4511	2·3334	4·4520	3·0520	1·1479	0·2146
30	1·6667	2·4833	2·1433	1·0750	0·2417	1·2500	2·3850	1·6350	0·6149	0·1150
30	0·5611	0·8360	0·7215	0·3619	0·0813	0·4208	0·8029	0·5504	0·2070	0·0387
..	9·4194	14·0347	12·1132	6·0754	1·3657	7·0646	13·4793	9·2405	3·4754	0·6497
10	0·4917	0·7326	0·6323	0·3171	0·0713	0·3687	0·7036	0·4823	0·1814	0·0339
10	0·0750	0·1118	0·0965	0·0484	0·0109	0·0563	0·1073	0·0736	0·0277	0·0052
10	3·2083	4·7805	4·1259	2·0694	0·4653	2·4063	4·5912	3·1475	1·1838	0·2213
10	0·8417	1·2541	1·0824	0·5429	0·1220	0·6312	1·2044	0·8257	0·3105	0·0580
10	0·0375	0·0559	0·0483	0·0242	0·0054	0·0282	0·0537	0·0368	0·0138	0·0026
10	3·0368	4·5249	3·9054	1·9588	0·4403	2·2776	4·3458	2·9792	1·1205	0·2094
10	0·4389	0·6539	0·5644	0·2831	0·0636	0·3291	0·6280	0·4305	0·1619	0·0303
10	0·8305	1·2375	1·0681	0·5357	0·1204	0·6229	1·1885	0·8148	0·3064	0·0573
..	8·9604	13·3512	11·5233	5·7796	1·2992	6·7203	12·8225	8·7904	3·3060	0·6180
30	3·0500	4·5445	3·9223	1·9672	0·4423	2·2875	4·3646	2·9921	1·1254	0·2104
30	1·2889	1·9204	1·6575	0·8313	0·1869	0·9667	1·8444	1·2644	0·4755	0·0889
30	4·4028	6·5602	5·6620	2·8399	0·6385	3·3021	6·3005	4·3193	1·6245	0·3037
30	0·3014	0·4491	0·3876	0·1944	0·0437	0·2260	0·4313	0·2957	0·1112	0·0208
..	9·0431	13·4742	11·6294	5·8328	1·3114	6·7823	12·9408	8·8715	3·3366	0·6238
10	0·1125	0·1676	0·1446	0·0725	0·0163	0·0843	0·1609	0·1103	0·0415	0·0078
10	0·1097	0·1635	0·1411	0·0708	0·0159	0·0823	0·1570	0·1076	0·0405	0·0076
..	0·2222	0·3311	0·2857	0·1433	0·0322	0·1666	0·3179	0·2179	0·0820	0·0154
..	355·5722	529·8024	457·2657	229·7441	51·5581	266·6791	508·8338	348·8265	131·1950	24·5238

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	14 0 18¾	257 1 0½	515 6 10	420 6 3	113 0 11	533·3583
12 set screws	.. ..	.. ..	0 1 0	0 1 0	0 1 7	0·1292
6 pairs of brasses. . . .	1 0 25	.. ..	6 17 0	5 2 9	0 8 0	5·5375
6 syphon taps	0 0 1¼	.. ..	0 1 3	0 0 10½	0 2 9	0·1813
Case-hardening pins and joints	.. ..	.. ..	0 10 4	0 10 4	8 6 10	8·8583
						14·7063
PISTON.						
2 piston blocks and cover .	1 1 20	.. ..	8 0 0	6 0 0	0 14 4	6·7167
2 ditto rods	.. ..	1 1 18	1 15 3	1 7 9	0 9 9	1·8750
4 ditto packings	0 0 15	.. ..	0 15 0	0 11 3	0 3 8	0·7458
2 ditto inside springs . .	0 0 7	.. ..	0 1 9	0 1 3¾	0 4 0	0·2656
10 bolts, fittings, &c. . .	.. ..	0 0 7	0 1 2	0 0 10	1 15 10	1·8334
2 ditto, inside rings . . .	.. ..	0 0 6	0 1 0	0 0 8	0 4 9	0·2708
						11·7073
2 cross-heads	.. ..	2 2 8	4 10 0	3 15 0	1 13 4	5·4167
2 spindles	.. ..	0 2 6	0 10 0	0 7 0	0 6 8	0·6833
4 cotters, fittings, &c. . .	.. ..	0 0 6	0 1 0	0 0 8	1 10 2	1·5417
						7·6417
4 slide blocks.	.. ..	0 2 7	0 3 5	0 1 5	0 13 0	0·7268
1 pump	1 0 16	.. ..	6 8 0	4 16 0	0 6 0	5·1000
1 gland	0 0 12	.. ..	0 12 0	0 9 0	0 0 9	0·4875
						5·5875
1 clack door	0 0 14	.. ..	0 14 0	0 10 6	0 1 0	0·5750
2 balls and clacks . . .	0 0 25½	.. ..	1 5 6	0 19 1½	0 3 11	1·1521
						1·7271
Studs, bolts, and nuts . .	.. ..	0 0 9½	0 0 10	0 0 5	0 1 10	0·1125
1 pump, ram, and fitting .	.. ..	0 2 0	0 8 0	0 5 0	0 12 9	0·8875
						1·0000
Carried forward . .	18 2 14½	263 0 12	548 3 4	445 7 1¾	131 1 10	576·4490

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	355·5722	529·8024	457·2657	229·7441	51·5581	266·6791	508·8338	348·8265	131·1950	24·5238
..										
10	0·0861	0·1283	0·1108	0·0555	0·0125	0·0646	0·1233	0·0845	0·0318	0·0059
10	3·6316	5·5006	4·7474	2·3811	0·5353	2·7688	5·2829	3·6216	1·3621	0·2546
10	0·1209	0·1801	0·1554	0·0780	0·0175	0·0906	0·1730	0·1186	0·0446	0·0083
10	5·9056	8·7993	7·5945	3·8090	0·8563	4·4291	8·4510	5·7935	2·1790	0·4073
..	9·8042	14·6083	12·6081	6·3236	1·4216	7·3531	14·0302	9·6182	3·6175	0·6761
10	4·4778	6·6719	5·7585	2·8882	0·6494	3·3584	6·4079	4·3929	1·6522	0·3088
10	1·2500	1·8625	1·6079	0·8062	0·1812	0·9375	1·7888	1·2263	0·4612	0·0862
10	0·4972	0·7408	0·6394	0·3207	0·0721	0·3729	0·7115	0·4878	0·1834	0·0343
10	0·1771	0·2638	0·2277	0·1142	0·0257	0·1328	0·2534	0·1737	0·0653	0·0122
10	1·2223	1·8212	1·5717	0·7883	0·1772	0·9167	1·7490	1·1990	0·4510	0·0843
10	0·1805	0·2690	0·2322	0·1164	0·0262	0·1354	0·2583	0·1771	0·0666	0·0124
..	7·8049	11·6292	10·0374	5·0340	1·1318	5·8537	11·1689	7·6568	2·8797	0·5382
30	3·6111	5·3807	4·6438	2·3292	0·5236	2·7084	5·1676	3·5426	1·3324	0·2490
30	0·4555	0·6787	0·5858	0·2939	0·0660	0·3116	0·6519	0·4469	0·1681	0·0314
30	1·0278	1·5314	1·3217	0·6630	0·1490	0·7709	1·4707	1·0082	0·3792	0·0709
..	5·0944	7·5908	6·5513	3·2861	0·7386	3·8209	7·2902	4·9977	1·8797	0·3513
15	0·4806	0·7160	0·6180	0·3099	0·0697	0·3604	0·6877	0·4714	0·1773	0·0331
30	3·4000	5·0660	4·3723	2·1931	0·4930	2·5500	4·8655	3·3355	1·2545	0·2345
30	0·3250	0·4842	0·4179	0·2096	0·0471	0·2437	0·4651	0·3188	0·1200	0·0224
..	3·7250	5·5502	4·7902	2·4027	0·5401	2·7937	5·3306	3·6543	1·3745	0·2569
30	0·3833	0·5712	0·4930	0·2472	0·0556	0·2875	0·5486	0·3761	0·1414	0·0264
30	0·7681	1·1444	0·9877	0·4954	0·1114	0·5760	1·0991	0·7535	0·2834	0·0530
..	1·1514	1·7156	1·4807	0·7426	0·1670	0·8635	1·6477	1·1296	0·4248	0·0794
15	0·0750	0·1118	0·0964	0·0484	0·0109	0·0562	0·1073	0·0736	0·0277	0·0052
15	0·5917	0·8816	0·7609	0·3816	0·0858	0·4438	0·8467	0·5804	0·2183	0·0408
..	0·6667	0·9931	0·8573	0·4300	0·0967	0·5000	0·9540	0·6540	0·2460	0·0460
..	384·2994	572·6059	494·2087	248·2730	55·7236	288·2244	549·9431	377·0085	141·7945	26·5018

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.			Cost of Materials. Net.			Cost of Labour.			Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£. dec.
Brought forward . .	18 2 14½	263 0 12	548	3	4	445	7	1¾	131	1	10	576·4490
2 clack-boxes, bottoms, and covers	1 2 3	.. ..	8	11	0	6	8	3	0	5	3	6·6750
Bolts and nuts	.. ..	0 0 15	0	1	4	0	0	7	0	2	3	0·1417
2 balls and clacks, and clack-boxes	0 0 13½	.. ..	0	13	6	0	10	1¾	0	11	5	1·0770
1 pet cock	.. ..	.. ..	0	5	0	0	5	0	0	1	3	0·3125
1 rod and handle	.. ..	0 0 24	0	2	2	0	0	11	0	0	3	0·0583
1 pet pipo	0 0 2	.. ..	0	3	3	0	2	9	0	0	8	0·1708
Copper, top, feed-pipe	0 0 17	.. ..	1	1	11	0	17	8	0	1	6	0·9583
Flange for ditto	0 0 6	.. ..	0	6	0	0	4	6	0	0	2	0·2333
Elbow pipe	0 1 4½	.. ..	1	12	6	1	4	4½	0	0	9	1·2563
1 copper pipe	0 1 14	.. ..	2	14	3	2	3	9	0	2	0	2·2875
1 flange for ditto	0 0 2½	.. ..	0	2	6	0	1	10½	0	0	2	0·1021
												13·2729
1 expansion (water connection)	0 2 11½	.. ..	3	7	6	2	10	7½	0	17	4	3·3979
Bolts and nuts	.. ..	0 0 2	0	0	2	0	0	1	0	0	5	0·0250
2 large unions	0 0 17¾	.. ..	0	17	9	0	13	3	0	1	5	0·7333
												4·1562
2 clips for stubber	.. ..	0 0 6	0	0	6	0	0	2	0	1	0	0·0583
2 feed-pipes, stays, and bolts	.. ..	0 3 4	0	7	10	0	3	4	0	5	6	0·4417
1 brass dome top and 2 valves	1 1 26	.. ..	8	6	0	6	4	6	0	6	9	6·5625
Studs and nuts	.. ..	0 0 11½	0	1	4	0	0	7	0	1	10	0·1268
1 set of brass work (spring balances)	0 0 13½	.. ..	0	13	6	0	10	1½	0	17	4	1·3729
2 springs for ditto	.. ..	.. ..	0	5	0	0	5	0	0	8	7	0·6792
1 set wrought ironwork (complete)	.. ..	0 2 1½	0	9	2	0	6	2	0	10	7	0·8375
Ironwork forged	.. ..	0 0 15	0	2	5	0	1	8	0	14	1	0·7875
1 regulator head	.. ..	0 3 22	0	5	8	0	2	8	0	1	10	0·2250
2 springs (steel)	0 0 4	.. ..	0	1	0	0	0	9	0	0	6	0·0625
2 ditto ditto planed	.. ..	.. ..	..	..		..	..		..	..		.. ..
1 stuffing-box (fittings, &c.)	0 2 3	.. ..	2	19	0	2	4	3	1	3	6	3·3875
1 pipe, cast-iron	.. ..	1 0 0	0	6	0	0	2	0	0	2	5	0·2208
1 straight copper pipe	0 1 14	.. ..	1	19	5	1	8	11	0	2	1½	1·5522
2 flanges for ditto	0 1 15	.. ..	2	3	0	1	12	3	0	2	4½	1·7312
1 elbow pipe (cast-iron)	.. ..	0 3 0	0	4	6	0	1	6	0	2	5	0·1958
1 bent copper ditto	0 1 12	.. ..	1	17	6	1	7	6	0	7	6	1·7500
Flanges for ditto	0 1 0	.. ..	1	8	0	1	1	0	0	4	3	1·2625
Bolts and nuts for the above	.. ..	0 0 23	0	2	1	0	0	11	0	0	2	0·0542
												21·3021
Carried forward . .	25 1 25¾	267 3 27	589	14	1	476	4	2¼	138	19	5	615·1802

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	384·2994	572·6059	494·2087	248·2730	55·7236	288·2244	549·9431	377·0085	141·7945	26·5048
20	4·4500	6·6305	5·7228	2·8703	0·6452	3·3375	6·3681	4·3656	1·6419	0·3069
20	0·0945	0·1407	0·1215	0·0609	0·0137	0·0708	0·1352	0·0927	0·0349	0·0065
20	0·7180	1·0698	0·9234	0·4631	0·1041	0·5385	1·0275	0·7041	0·2649	0·0495
20	0·2083	0·3104	0·2679	0·1344	0·0302	0·1563	0·2981	0·2014	0·0769	0·0148
20	0·0389	0·0579	0·0500	0·0251	0·0056	0·0291	0·0556	0·0381	0·0143	0·0027
20	0·1139	0·1697	0·1464	0·0734	0·0165	0·0854	0·1629	0·1117	0·0420	0·0078
20	0·6389	0·9519	0·8216	0·4121	0·0926	0·4792	0·9142	0·6267	0·2357	0·0441
20	0·1555	0·2317	0·2000	0·1003	0·0226	0·1166	0·2226	0·1526	0·0574	0·0107
20	0·8375	1·2479	1·0771	0·5402	0·1214	0·6282	1·1985	0·8216	0·3090	0·0578
20	1·5250	2·2723	1·9612	0·9836	0·2211	1·1438	2·1823	1·4961	0·5627	0·1052
20	0·0681	0·1014	0·0875	0·0439	0·0099	0·0511	0·0974	0·0668	0·0251	0·0047
..	8·8186	13·1842	11·3794	5·7073	1·2829	6·6365	12·6624	8·6807	3·2648	0·6107
30	2·2653	3·3753	2·9131	1·4611	0·3285	1·6989	3·2417	2·2223	0·8358	0·1562
30	0·0166	0·0248	0·0214	0·0108	0·0024	0·0125	0·0238	0·0163	0·0061	0·0011
30	0·4889	0·7285	0·6288	0·3154	0·0709	0·3667	0·6996	0·4796	0·1804	0·0337
..	2·7708	4·1286	3·5633	1·7873	0·4018	2·0781	3·9651	2·7182	1·0223	0·1910
30	0·0389	0·0579	0·0500	0·0251	0·0056	0·0291	0·0556	0·0381	0·0143	0·0027
30	0·2945	0·4387	0·3787	0·1899	0·0427	0·2209	0·4213	0·2888	0·1086	0·0203
30	4·3750	6·5187	5·6263	2·8219	0·6344	3·2812	6·2608	4·2920	1·6142	0·3017
30	0·0805	0·1200	0·1036	0·0519	0·0117	0·0604	0·1152	0·0790	0·0297	0·0055
30	0·9153	1·3637	1·1771	0·5904	0·1326	0·6865	1·3098	0·8979	0·3377	0·0631
30	0·4528	0·6747	0·5823	0·2921	0·0657	0·3396	0·6480	0·4442	0·1671	0·0312
30	0·5583	0·8319	0·7180	0·3600	0·0810	0·4187	0·7990	0·5477	0·2060	0·0385
30	0·5250	0·7823	0·6751	0·3386	0·0761	0·3938	0·7513	0·5150	0·1937	0·0362
30	0·1500	0·2235	0·1929	0·0967	0·0217	0·1125	0·2147	0·1472	0·0553	0·0103
30	0·0417	0·0621	0·0536	0·0269	0·0061	0·0312	0·0596	0·0409	0·0154	0·0028
30	..	..	..	..	..	..	..	..	..	..
30	2·2583	3·3649	2·9042	1·4566	0·3275	1·6938	3·2317	2·2153	0·8333	0·1558
30	0·1472	0·2193	0·1893	0·0949	0·0213	0·1104	0·2106	0·1444	0·0543	0·0101
30	1·0348	1·5417	1·3307	0·6674	0·1500	0·7761	1·4807	1·0151	0·3818	0·0714
30	1·1541	1·7197	1·4841	0·7445	0·1674	0·8656	1·6516	1·1322	0·4258	0·0796
30	0·1305	0·1946	0·1679	0·0842	0·0189	0·0979	0·1868	0·1281	0·0482	0·0090
30	1·1667	1·7381	1·5003	0·7526	0·1692	0·8750	1·6695	1·1445	0·4304	0·0804
30	0·8417	1·2541	1·0824	0·5429	0·1221	0·6312	1·2044	0·8257	0·3105	0·0580
30	0·0361	0·0538	0·0465	0·0233	0·0052	0·0271	0·0517	0·0354	0·0133	0·0025
..	14·2014	21·1600	18·2630	9·1599	2·0592	10·6510	20·3223	13·9317	5·2396	0·9791
..	410·1202	611·0787	527·4144	264·9275	59·4675	307·5900	586·8929	402·3391	151·3212	28·2856

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	25 1 25¾	267 3 27	589 14 1	476 4 2½	138 19 5	615·1802
1 brass valve	0 0 20½	.. ..	1 0 6	0 15 4½	0 2 5	0·8896
1 cast-iron ditto	.. ..	.. ..	0 0 6	0 0 6	0 0 1	0·0292
1 set of wrought ironwork (complete)	.. ..	1 0 20	0 11 9	0 5 9	0 15 11	1·0833
						2·0021
1 small spring	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
1 warming cock	.. ..	.. ..	1 15 0	1 15 0	0 1 1½	1·8062
1 ditto pipe	0 0 14	.. ..	1 3 4	0 19 10	0 0 7½	1·0229
4 studs and nuts	.. ..	0 0 2	0 0 2	0 0 1	0 0 6	0·0292
1 pipe in fire-box. . . .	0 0 8	.. ..	0 13 4	0 11 4	0 0 4	0·5833
						3·4416
1 blast pipe	0 1 8	.. ..	1 13 9	1 4 9	0 2 4	1·3542
1 flange	0 0 12	.. ..	0 12 0	0 9 0	0 0 10	0·4916
6 studs and nuts	.. ..	0 0 5	0 0 5	0 0 2½	0 1 0	0·0604
						1·9062
BOILER.						
2 fire-box brackets . . .	.. ..	4 3 24	12 8 3	10 19 9	0 17 10	11·8792
2 smoke-boxes	.. ..	4 1 2	10 13 4	9 7 10	0 15 2	10·1500
3 plates for expansion brackets	.. ..	0 3 19	0 9 2	0 4 8	0 3 3	0·3958
Studs and nuts	.. ..	0 0 10	0 0 11	0 0 5	0 1 5	0·0917
2 expansion brackets . .	2 0 20	.. ..	12 4 0	9 3 0	0 6 0	9·4500
2 plates for ditto	.. ..	0 2 1	0 5 1	0 2 1	0 2 6	0·2292
28 nuts and bolts	.. ..	0 0 21	0 1 11	0 0 10	0 3 3	0·2042
4 syphon caps and covers .	0 0 10	.. ..	0 10 0	0 7 6	2 1 2½	2·4354
4 covers	.. ..	0 0 2	0 0 2	0 0 1	0 0 5½	0·0271
						34·8626
4 iron plates for smoke-box and drag plates . . .	.. ..	7 3 2	8 10 11	6 4 5	1 1 11	7·3167
1 manhole door	.. ..	1 1 10	2 0 2	1 12 8	0 5 9	1·9208
2 fire-box shell ends . . .	.. ..	9 2 22	15 10 3	12 13 3	2 4 6½	14·8896
2 iron shell sides	.. ..	10 2 12	19 12 5	16 9 5	2 17 11½	19·3687
1 smoke-box front plate . .	.. ..	3 3 12	5 8 0	4 5 6	0 15 0½	5·0271
2 tube plates and back fire-box	.. ..	14 2 5	29 1 9	24 14 9	4 7 1	29·0917
6 ditto barrel fire-box and dome	.. ..	36 3 11	82 18 2	71 17 8	12 12 11½	84·5312
						162·1458
Carried forward . .	28 2 6¼	364 3 11	796 19 4	650 9 10¼	169 0 11	819·5385

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	410·1202	611·0787	527·4144	264·9275	59·4675	307·5900	586·8929	402·3391	151·3212	28·2856
..										
10	0·5930	0·8836	0·7626	0·3825	0·0860	0·4448	0·8487	0·5818	0·2188	0·0409
10	0·0195	0·0290	0·0250	0·0126	0·0028	0·0146	0·0279	0·0191	0·0072	0·0013
10	0·7222	1·0762	0·9288	0·4658	0·1047	0·5417	1·0335	0·7085	0·2665	0·0498
..	1·3347	1·9888	1·7164	0·8609	0·1935	1·0011	1·9101	1·3094	0·4925	0·0920
..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
30	1·2041	1·7942	1·5485	0·7767	0·1746	0·9031	1·7231	1·1813	0·4443	0·0830
30	0·6819	1·0161	0·8770	0·4398	0·0989	0·5114	0·9759	0·6690	0·2516	0·0470
30	0·0195	0·0290	0·0250	0·0125	0·0028	0·0146	0·0278	0·0191	0·0072	0·0013
30	0·3889	0·5794	0·5000	0·2508	0·0564	0·2917	0·5565	0·3815	0·1435	0·0268
..	2·2944	3·4187	2·9505	1·4798	0·3327	1·7208	3·2833	2·2509	0·8466	0·1581
15	0·9028	1·3452	1·1609	0·5823	0·1309	0·6771	1·2919	0·8857	0·3331	0·0623
15	0·3277	0·4883	0·4215	0·2114	0·0475	0·2458	0·4691	0·3216	0·1209	0·0226
15	0·0403	0·0600	0·0518	0·0260	0·0058	0·0302	0·0576	0·0395	0·0149	0·0028
..	1·2708	1·8935	1·6342	0·8197	0·1842	0·9531	1·8186	1·2468	0·4689	0·0877
30	7·9195	11·8000	10·1845	5·1082	1·1484	5·9396	11·3330	7·7692	2·9220	0·5462
30	6·7666	10·0823	8·7019	4·3645	0·9812	5·0750	9·6833	6·6381	2·4967	0·4667
30	0·2639	0·3932	0·3393	0·1702	0·0383	0·1979	0·3776	0·2589	0·0974	0·0182
30	0·0611	0·0910	0·0786	0·0394	0·0089	0·0458	0·0875	0·0600	0·0226	0·0042
30	6·3060	9·3871	8·1019	4·0635	0·9135	4·7250	9·0155	6·1805	2·3245	0·4351
30	0·1528	0·2277	0·1965	0·0985	0·0221	0·1146	0·2187	0·1500	0·0564	0·0105
30	0·1361	0·2028	0·1751	0·0878	0·0197	0·1021	0·1948	0·1335	0·0502	0·0094
30	1·6236	2·4191	2·0880	1·0473	0·2354	1·2177	2·3234	1·5928	0·5991	0·1120
30	0·0181	0·0269	0·0232	0·0116	0·0026	0·0136	0·0258	0·0177	0·0067	0·0012
..	23·2417	34·6301	29·8890	14·9910	3·3701	17·4313	33·2596	22·8007	8·5756	1·6035
10	4·8778	7·2679	6·2728	3·1462	0·7073	3·6583	6·9803	4·7853	1·7998	0·3364
10	1·2805	1·9080	1·6468	0·8259	0·1857	0·9604	1·8325	1·2562	0·4725	0·0883
10	9·9264	14·7903	12·7659	6·4025	1·4393	7·4448	14·2050	9·7381	3·6625	0·6846
10	12·9125	19·2396	16·6054	8·3286	1·8723	9·6844	18·4781	12·6675	4·7643	0·8906
10	3·3514	4·9936	4·3099	2·1617	0·4859	2·5135	4·7960	3·2878	1·2366	0·2311
10	19·3945	28·8978	24·9413	12·5094	2·8122	14·5459	27·7541	19·0266	7·1560	1·3376
10	56·3541	83·9676	72·4716	36·3484	8·1713	42·2656	80·6445	55·2851	20·7930	3·8867
..	108·0972	161·0648	139·0137	69·7227	15·6740	81·0729	154·6905	106·0466	39·8817	7·4553
..	546·3590	814·0746	702·6182	352·8018	79·2220	409·7690	781·8550	535·9935	201·5895	37·6822

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	28 2 6¼	364 3 11	796 19 4	650 9 10¼	169 0 11	819·5385
1 ditto front	.. ..	6 1 5	11 12 11	9 15 5	1 14 4½	11·4896
3 copper plates	13 1 5	.. ..	71 7 0	52 14 9	9 5 7	62·0167
2 ditto hammered ditto . .	12 1 8	.. ..	71 17 6	54 12 6	9 12 3	64·2376
Ditto rods.	5 1 14	.. ..	37 12 6	30 2 0	5 5 11	35·3959
Ditto rivets	0 3 24	.. ..	6 15 0	5 8 0	0 19 0	6·3500
Brass ring	1 0 16	.. ..	6 8 0	4 16 0	0 16 10½	5·6437
Bar iron for stays . . .	.. ..	3 2 10	2 5 0	1 4 0	0 4 3	1·4125
Ditto bolts and nuts . . .	.. ..	1 2 0	0 18 9	0 9 9	0 1 8½	0·5729
Ditto rivets	.. ..	7 2 19	8 1 1	5 16 1	1 0 5	6·8250
T iron	.. ..	3 0 16	3 9 2	2 11 2	0 9 0	3·0083
Angle-iron frame (smoke-box) and angle-iron frame (fire-box)	.. ..	3 2 23	4 1 6	3 0 6	0 10 8	3·5583
Roof stays and works to the above	.. ..	10 1 14	20 15 0	17 13 6	3 2 2½	20·7854
						221·2953
177 brass tubes	45 3 9	.. ..	224 1 5	159 18 2	1 17 3½	161·7729
354 steel ferrules. . . .	.. ..	0 3 6	0 13 8	0 9 2	0 0 1½	0·4646
						162·2375
Chimney	.. ..	.. ..	4 0 0	4 0 0	0 14 6	4·7250
10 bolts and nuts . . .	.. ..	0 0 10	0 0 11	0 0 5	0 1 6	0·0957
						4·8207
1 ash pan and door . . .	.. ..	.. ..	1 19 9	1 19 9	0 10 4	2·5041
1 set of ironwork. . . .	.. ..	0 2 12	0 6 1	0 3 1	0 5 6	0·4292
1 pair sliding fire-doors .	.. ..	0 2 12	0 6 1	0 3 1	0 11 5	0·7250
1 set of ironwork to ditto .	.. ..	0 2 11	0 6 0	0 3 0	0 11 1	0·7042
1 fender	.. ..	.. ..	0 3 0	0 3 0	0 11 1	0·7042
						5·0667
1 angle-iron ring for smoke-box door	.. ..	1 1 10	1 9 6	1 2 0	0 11 9	1·6875
2 plates for ditto. . . .	.. ..	1 3 8	0 19 2	0 8 8	0 3 8	0·6167
1 set wrought ironwork . .	.. ..	0 1 22½	0 4 6	0 3 0	1 14 6	1·8750
						4·1792
Carried forward . .	107 1 26¼	407 1 21½	1276 12 10	1007 6 10¼	269 15 11	1217·1385

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years	546·3590	814·0746	702·6182	352·8018	79·2220	409·7690	781·8550	535·9935	201·5895	37·6822
..										
10	7·6597	11·4130	9·8503	4·9405	1·1107	5·7448	10·9613	7·5144	2·8262	0·5283
10	41·3445	61·6033	53·1690	26·6672	5·9950	31·0083	59·1652	40·5601	15·2548	2·8515
10	42·8251	63·8092	55·0728	27·6221	6·2095	32·1188	61·2839	42·0126	15·8011	2·9536
10	23·5973	35·1598	30·3460	15·2202	3·4216	17·6979	33·7683	23·1496	8·7066	1·6275
10	4·2333	6·3077	5·4440	2·7305	0·6138	3·1750	6·0580	4·1530	1·5620	0·2920
10	3·7625	5·6061	4·8384	2·4268	0·5456	2·8219	5·3841	3·6911	1·3882	0·2595
10	0·9417	1·4031	1·2110	0·6074	0·1365	0·7063	1·3475	0·9238	0·3474	0·0649
10	0·3819	0·5691	0·4912	0·2463	0·0554	0·2864	0·5465	0·3747	0·1409	0·0263
10	4·5500	6·7795	5·8513	2·9347	0·6598	3·4125	6·5112	4·4637	1·6788	0·3138
10	2·0055	2·9883	2·5790	1·2936	0·2909	1·5042	2·8700	1·9675	0·7400	0·1383
10	2·3722	3·5346	3·0506	1·5302	0·3440	1·7792	3·3947	2·3272	0·8753	0·1636
10	13·8569	20·6468	17·8200	8·9378	2·0093	10·3927	19·8297	13·5941	5·1129	0·9557
..	147·5306	219·8205	189·7236	95·1573	21·3921	110·6480	211·1204	144·7318	54·4342	10·1750
5	107·8486	160·6944	138·6933	69·5623	15·6381	80·8864	154·3346	105·8027	39·7929	7·4383
5	0·3097	0·4615	0·3983	0·1998	0·0449	0·2323	0·4432	0·3039	0·1143	0·0214
..	108·1583	161·1559	139·0916	69·7621	15·6830	81·1187	154·7778	106·1066	39·9072	7·4597
10	3·1500	4·6935	4·0509	2·0317	0·4568	2·3625	4·5077	3·0902	1·1622	0·2173
10	0·0638	0·0952	0·0821	0·0412	0·0093	0·0478	0·0914	0·0627	0·0236	0·0044
..	3·2138	4·7887	4·1330	2·0729	0·4661	2·4103	4·5991	3·1529	1·1858	0·2217
15	1·6694	2·4875	2·1469	1·0768	0·2421	1·2521	2·3891	1·6378	0·6160	0·1151
15	0·2861	0·4263	0·3680	0·1846	0·0415	0·2146	0·4095	0·2807	0·1056	0·0197
15	0·4833	0·7201	0·6215	0·3118	0·0700	0·3625	0·6917	0·4742	0·1783	0·0333
15	0·4695	0·6995	0·6037	0·3027	0·0681	0·3521	0·6718	0·4606	0·1732	0·0324
15	0·4695	0·6995	0·6037	0·3028	0·0681	0·3521	0·6718	0·4606	0·1732	0·0324
..	3·3778	5·0329	4·3438	2·1787	0·4898	2·5334	4·8339	3·3139	1·2463	0·2329
20	1·1250	1·6763	1·4467	0·7256	0·1631	0·8437	1·6099	1·1037	0·4151	0·0776
20	0·4111	0·6126	0·5287	0·2652	0·0596	0·3084	0·5883	0·4033	0·1517	0·0284
20	1·2500	1·8625	1·6075	0·8063	0·1812	0·9375	1·7888	1·2263	0·4612	0·0862
..	2·7861	4·1514	3·5829	1·7971	0·4039	2·0896	3·9870	2·7333	1·0280	0·1922
..	811·4256	1209·0240	1043·4931	523·7699	117·6569	608·5690	1161·1732	796·0320	299·3910	55·9637

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	107 1 26¼	407 1 21½	1276 12 10	1007 6 10¼	209 15 11	1217·1385
Water gauge	.. ..	.. ..	1 6 8	1 6 8	0 6 6	1·6583
8 studs and nuts	.. ..	0 0 4	0 0 4	0 0 1	0 0 6	0·0292
1 waste water-pipe . . .	0 0 3	.. ..	0 2 9	0 2 0	0 0 1	0·1042
1 injector, No. 8	.. ..	.. ..	27 0 0	27 0 0	2 2 6	29·1250
1 ditto cock	.. ..	.. ..	1 5 0	1 5 0	0 2 0	1·3500
4 brass flanges	0 0 15½	.. ..	0 15 6	0 11 7½	0 0 11	0·6271
						32·8938
1 brass elbow	0 0 8	.. ..	0 8 0	0 6 0	0 0 6	0·3250
1 ditto union	0 0 12	.. ..	0 12 0	0 9 0	0 0 8½	0·4854
1 ditto thread end . . .	0 0 4	.. ..	0 4 0	0 3 0	0 0 3	0·1625
Copper pipes	0 3 0	.. ..	7 0 0	5 19 0	0 9 4	6·4167
Wrought iron.	.. ..	0 2 6	0 5 6	0 2 6	0 0 2½	0·1354
2 gauge cocks.	.. ..	.. ..	0 9 0	0 9 0	0 0 4	0·4667
1 funnel and pipe . . .	0 0 7	.. ..	0 6 3	0 4 6	0 0 2	0·2333
2 studs and nuts . . .	.. ..	0 0 3	0 0 3	0 0 1	0 0 6	0·0292
2 spectacle plates. . . .	.. ..	5 1 18	8 13 2	7 1 8	0 19 9	8·0708
Angle irons	.. ..	2 0 0	1 0 0	0 8 0	1 2 3	1·5125
Bolts, nuts, &c.	.. ..	0 0 8	0 0 9	0 0 4	0 0 11	0·0625
1 large angle iron . . .	.. ..	0 2 0	0 11 0	0 8 0	0 15 11	1·1959
2 tallow cocks and couplings	.. ..	.. ..				
1 pipe for ditto	.. ..	.. ..	0 1 0	0 1 0	0 0 6	0·0750
2 lead plugs	.. ..	.. ..				
						19·1709
8 washing out plugs. . .	0 0 13¼	.. ..	0 13 3	0 9 9	0 4 0	0·6875
1 pressure gauge . . .	.. ..	.. ..	2 15 0	2 15 0	0 4 5	2·9708
1 union pipe and 6 screws .	.. ..	.. ..	0 4 5	0 4 5	0 0 4	0.2375
						3·8958
1 whistle and stand . . .	.. ..	.. ..	1 1 0	1 1 0	.. ..	1·0500
1 ditto pipe, ditto machines.	0 0 2	.. ..	0 3 3	0 2 9	0 0 3	0·1500
1 rod and handle. . . .	.. ..	0 0 3	0 0 3	0 0 1	0 0 11	0·0500
3 brass handrails. . . .	0 2 12	.. ..	2 19 6	2 2 6	0 2 11	2·2708
Brackets and ends for ditto.	0 1 9	.. ..	1 17 0	1 7 9	0 1 11	1·4833
						5·0041
8 iron handrails	.. ..	0 1 16	0 3 11	0 2 5	0 7 10	0·5125
12 studs and nuts . . .	.. ..	0 0 8	0 0 8	0 0 3	0 0 10	0·0542
1 blow-through cock. . .	0 0 4	.. ..	0 4 0	0 3 0	0 3 6	0·3250
1 set of ironwork. . . .	.. ..	0 1 0	0 2 6	0 1 0	0 11 0	0·6000
						1·4917
Carried forward . .	109 3 4	416 3 3½	1336 18 9	1061 14 2⅔	217 17 8	1279·5948

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	811·4256	1200·0240	1043·4931	523·7699	117·6569	608·5690	1161·1732	796·0320	299·3910	55·9637
..										
30	1·1055	1·6473	1·4217	0·7131	0·1603	0·8291	1·5820	1·0846	0·4079	0·0762
30	0·0195	0·0289	0·0249	0·0125	0·0028	0·0146	0·0277	0·0190	0·0072	0·0013
30	0·0694	0·1035	0·0893	0·0448	0·0100	0·0521	0·0994	0·0681	0·0256	0·0048
30	19·4167	28·9307	24·9699	12·5237	2·8154	14·5625	27·7858	19·0483	7·1642	1·3392
30	0·9000	1·3410	1·1575	0·5805	0·1306	0·6750	1·2879	0·8829	0·3321	0·0621
30	0·4181	0·6229	0·5377	0·2697	0·0606	0·3136	0·5982	0·4101	0·1542	0·0288
..	21·9292	32·6743	28·2010	14·1443	3·1797	16·4469	31·3810	21·5130	8·0912	1·5124
30	0·2167	0·3228	0·2786	0·1397	0·0314	0·1625	0·3101	0·2125	0·0800	0·0149
30	0·3236	0·4822	0·4161	0·2087	0·0469	0·2427	0·4631	0·3174	0·1194	0·0223
30	0·1083	0·1614	0·1393	0·0699	0·0157	0·0812	0·1550	0·1063	0·0400	0·0075
30	4·2778	6·3741	5·5011	2·7592	0·6203	3·2084	6·1217	4·1966	1·5784	0·2954
30	0·0903	0·1345	0·1161	0·0583	0·0131	0·0677	0·1292	0·0866	0·0333	0·0062
30	0·3111	0·4636	0·4001	0·2007	0·0452	0·2333	0·4452	0·3052	0·1148	0·0215
30	0·1555	0·2317	0·2000	0·1003	0·0225	0·1167	0·2226	0·1526	0·0574	0·0107
30	0·0195	0·0290	0·0250	0·0125	0·0028	0·0146	0·0278	0·0191	0·0072	0·0013
30	5·3805	8·0170	6·9195	3·4704	0·7802	4·0354	7·6997	5·2784	1·9853	0·3711
30	1·0083	1·5024	1·2967	0·6504	0·1462	0·7562	1·4430	0·9892	0·3720	0·0695
30	0·0417	0·0621	0·0536	0·0269	0·0061	0·0313	0·0596	0·0409	0·0154	0·0029
30	0·7973	1·1878	1·0253	0·5142	0·1156	0·5979	1·1408	0·7821	0·2941	0·0550
30	0·0500	0·0745	0·0643	0·0322	0·0072	0·0375	0·0715	0·0490	0·0184	0·0034
..	12·7806	19·0431	16·4357	8·2434	1·8532	9·5854	18·2893	12·5359	4·7157	0·8817
7	0·4583	0·6829	0·5894	0·2956	0·0665	0·3437	0·6559	0·4496	0·1691	0·0316
7	1·9805	2·9510	2·5470	1·2774	0·2871	1·4854	2·8342	1·9430	0·7308	0·1366
7	0·1584	0·2359	0·2036	0·1022	0·0230	0·1188	0·2266	0·1553	0·0584	0·0109
..	2·5972	3·8698	3·3400	1·6752	0·3766	1·9479	3·7167	2·5479	0·9583	0·1791
15	0·7000	1·0429	0·9002	0·4515	0·1015	0·5250	1·0017	0·6867	0·2583	0·0483
15	0·1000	0·1490	0·1286	0·0645	0·0145	0·0750	0·1431	0·0981	0·0369	0·0069
15	0·0333	0·0497	0·0429	0·0215	0·0048	0·0250	0·0477	0·0327	0·0123	0·0023
15	1·5139	2·2557	1·9469	0·9765	0·2195	1·1354	2·1664	1·4851	0·5586	0·1044
15	0·9889	1·4735	1.2717	0·6378	0·1434	0·7417	1·4151	0·9701	0·3659	0·0682
..	3·3361	4·9708	4·2903	2·1518	0·4837	2·5021	4·7740	3·2727	1·2320	0·2301
30	0·3117	0·5090	0·4394	0·2204	0·0496	0·2562	0·4889	0·3352	0·1261	0·0236
30	0·0361	0·0539	0·0464	0·0233	0·0052	0·0271	0·0517	0·0354	0·0133	0·0025
30	0·2167	0·3228	0·2786	0·1397	0·0314	0·1625	0·3100	0·2126	0·0800	0·0149
30	0·4000	0·5960	0·5144	0·2580	0·0580	0·3000	0·5724	0·3924	0·1476	0·0276
..	0·9945	1·4817	1·2788	0·6414	0·1442	0·7458	1·4230	0·9756	0·3670	0·0686
..	853·0632	1271·0637	1097·0389	550·6260	123·6943	639·7971	1220·7572	836·8771	314·7552	58·8356

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	109 3 4	416 3 3½	1336 18 9	1061 14 2¾	217 17 8	1279·5948
998 feet timber lagging . .	.. ..	.. ..	3 2 5	3 2 5	1 0 7	4·1500
2 stoops for ditto	.. ..	.. ..	0 4 0	0 4 0	0 1 4	0·2667
Nails and screws	.. ..	0 0 2	0 0 4	0 0 3	0 0 1	0·0167
						4·4334
Sheets of iron	.. ..	8 0 0	5 8 0	3 0 0	0 3 9	3·1875
Iron hoops and screws . .	.. ..	1 0 12	0 14 11	0 8 11	0 0 7	0·4750
1 brass ring (dome) . . .	0 0 3½	.. ..	0 3 6	0 2 7½	0 0 2	0·1396
2 iron ditto (jack-box) . .	.. ..	0 0 7	0 0 7	0 0 3	.. ..	0·0125
Screws (putting on) . . .	.. ..	0 0 6	0 1 6	0 1 2	8 13 1	3·7125
1 dome cover	1 1 0	.. ..	6 11 3	4 16 3	1 8 0	6·2125
1 manhole ditto	0 1 0	.. ..	1 6 3	0 19 3	0 14 0	1·6625
2 brass corner pieces . .	0 3 0	.. ..	3 10 0	2 9 0	0 19 0	3·4000
Fire bars and frames . .	.. ..	.. ..	3 13 0	3 13 0	0 12 5	4·2708
						28·0729
Painting, &c., &c. . . .	.. ..	.. ..	3 14 8	3 14 8	4 10 0	8·2333
Erector's contract . . .	.. ..	.. ..	.. ..	.. ..	38 5 0	38·2500
Jet cock and union . . .	.. ..	.. ..	1 8 0	1 8 0	0 3 3½	1·5646
Copper pipes	0 0 14	.. ..	1 2 9	0 19 3	0 2 3	1·0750
Ironwork	.. ..	0 1 0	0 2 6	0 1 0	0 0 1½	0·0562
						2·6958
FRAMING.						
Frame stays (smithed) . .	.. ..	2 1 20	1 18 10	1 5 4	1 18 6	3·1917
12 horn blocks	.. ..	9 1 20	2 16 7	0 19 7	1 1 5	2·0500
Bolts	.. ..	1 1 16	0 13 11	0 6 5	1 17 1	2·1750
2 outside frames (solid) .	.. ..	57 3 14	56 8 7	39 2 1	12 14 2	51·8125
2 stays for inside frames .	.. ..	0 2 24	0 7 2	0 4 2	0 10 10	0·7500
4 horn blocks	.. ..	2 0 14	0 12 9	0 4 9	0 7 3	0·6000
Bolts	.. ..	0 1 7	0 3 2	0 1 8	0 9 3	0·5458
2 inside frame plates. . .	.. ..	26 0 20	25 10 6	17 14 6	4 2 2	21·8333
Horn stays	.. ..	2 0 24	1 15 5	1 3 5	0 15 11	1·9667
2 angle irons for footplates .	.. ..	0 0 20	0 3 11	0 2 11	0 2 8½	0·2812
6 studs	.. ..	0 0 6	0 0 6	0 0 2	0 0 2	0·0167
11 plates for ditto and round engine	.. ..	8 3 19	4 0 3	1 7 9	1 5 11½	2·6854
2 ditto for angle irons for footplate stays	.. ..	2 1 1	2 9 8	1 16 2	1 13 10	3·5000
						91·4083
Carried forward . .	112 0 21½	540 1 11½	1465 3 8	1151 3 2¼	301 10 6	1452·6885

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.	853·0632	1271·0637	1097·0389	550·6260	123·6943	639·7971	1220·7572	836·8771	314·7552	58·8356
..										
10	2·7667	4·1223	3·5580	1·7845	0·4012	2·0750	3·9592	2·7142	1·0208	0·1908
10	0·1778	0·2649	0·2286	0·1147	0·0258	0·1333	0·2544	0·1744	0·0656	0·0123
10	0·0111	0·0165	0·0142	0·0071	0·0015	0·0084	0·0159	0·0109	0·0041	0·0008
..	2·9556	4·4037	3·8008	1·9063	0·4285	2·2167	4·2295	2·8995	1·0905	0·2039
30	2·1250	3·1663	2·7328	1·3706	0·3081	1·5937	3·0409	2·0847	0·7841	0·1466
30	0·3167	0·4718	0·4072	0·2042	0·0459	0·2375	0·4532	0·3147	0·1168	0·0218
30	0·0931	0·1387	0·1197	0·0601	0·0135	0·0698	0·1332	0·0913	0·0343	0·0064
30	0·0083	0·0124	0·0107	0·0054	0·0012	0·0063	0·0119	0·0082	0·0031	0·0006
30	5·8083	8·6546	7·4696	3·7464	0·8422	4·3563	8·3119	5·6981	2·1431	0·4006
30	4·1417	6·1712	5·3263	2·6713	0·6005	3·1063	5·9268	4·0631	1·5281	0·2856
30	1·1083	1·6514	1·4253	0·7149	0·1607	0·8312	1·5861	1·0873	0·4089	0·0764
30	2·2667	3·3773	2·9149	1·4620	0·3287	1·7000	3·2437	2·2237	0·8363	0·1563
30	2·8472	4·2423	3·6615	1·8364	0·4128	2·1354	4·0744	2·7932	1·0505	0·1964
..	18·7153	27·8860	24·0680	12·0713	2·7136	14·0365	26·7821	18·3643	6·9052	1·2907
4	5·4889	8·1784	7·0586	3·5403	0·7959	4·1167	7·8547	5·3847	2·0252	0·3786
30	25·5000	37·9950	32·7931	16·4476	3·6976	19·1250	36·4913	25·0163	9·4087	1·7587
15	1·0431	1·5542	1·3414	0·6728	0·1513	0·7823	1·4927	1·0233	0·3849	0·0719
15	0·7167	1·0678	0·9216	0·4623	0·1039	0·5375	1·0256	0·7031	0·2644	0·0494
15	0·0374	0·0558	0·0482	0·0242	0·0054	0·0281	0·0536	0·0368	0·0138	0·0026
..	1·7972	2·6778	2·3112	1·1593	0·2606	1·3479	2·5719	1·7632	0·6631	0·1239
30	2·1278	3·1704	2·7363	1·3724	0·3085	1·5958	3·0449	2·0874	0·7851	0·1467
30	1·3667	2·0363	1·7575	0·8815	0·1982	1·0250	1·9557	1·3407	0·5043	0·0943
30	1·4500	2·1605	1·8647	0·9352	0·2102	1·0875	2·0750	1·4225	0·5350	0·1000
30	34·5417	51·4671	44·4206	22·2794	5·0085	25·9063	49·4302	33·8864	12·7448	2·3823
30	0·5000	0·7450	0·6430	0·3225	0·0725	0·3750	0·7155	0·4905	0·1845	0·0345
30	0·4000	0·5960	0·5144	0·2580	0·0580	0·3000	0·5724	0·3924	0·1476	0·0276
30	0·3639	0·5422	0·4679	0·2347	0·0528	0·2729	0·5207	0·3570	0·1343	0·0251
30	14·5555	21·6877	18·7185	9·3884	2·1106	10·9167	20·8294	14·2794	5·3705	1·0039
30	1·3111	1·9536	1·6861	0·8457	0·1901	0·9834	1·8763	1·2863	0·4837	0·0904
30	0·1875	0·2794	0·2412	0·1209	0·0272	0·1406	0·2683	0·1839	0·0692	0·0129
30	0·0111	0·0166	0·0143	0·0073	0·0016	0·0083	0·0159	0·0109	0·0041	0·0008
30	1·7903	2·6676	2·3023	1·1547	0·2596	1·3427	2·5619	1·7563	0·6605	0·1235
30	2·3334	3·4766	3·0007	1·5050	0·3383	1·7500	3·3391	2·2891	0·8609	0·1601
..	60·9390	90·7990	78·3675	39·3057	8·8361	45·7042	87·2053	59·7828	22·4845	4·2021
..	968·1592	1443·0036	1245·4381	625·0565	140·4266	726·3441	1385·8920	950·0879	357·3324	66·7935

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	112 0 21½	540 1 11½	1465 3 8	1151 3 2¼	301 10 6	1452·6885
6 plates for handrails . .	.. ..	2 0 16	0 19 4	0 7 4	0 2 8½	0·5021
Angle irons	.. ..	0 2 0	0 11 0	0 8 0	0 2 11½	0·5479
Rivets	.. ..	0 1 10	0 7 2	0 5 8	0 2 1	0·3875
2 handrail columns and top rail	.. ..	0 3 2	0 7 8	0 3 2	0 8 0	0·5583
2 brass knobs.	0 0 2½	.. ..	0 2 6	0 1 10½	0 4 9	0·3312
4 washers	.. ..	0 2 5	0 8 9	0 5 9	0 5 8	0·5708
Foot steps	.. ..	1 3 2	0 17 8	0 7 2	0 1 2	0·4167
6 splashers	.. ..	0 3 9	0 7 6	0 3 0	0 7 0	0·5000
Angle-iron heading . . .	.. ..	0 3 0	0 16 6	0 12 0	1 8 0	2·0000
12 splasher feet	.. ..	0 3 1	0 13 8	0 9 2	1 1 5	1·5292
Ditto bolts	.. ..	.. ..	0 2 0	0 2 0	0 4 8	0·3333
						7·0770
2 buffer planks	.. ..	.. ..	1 15 9	1 15 9	0 18 0	2·6875
2 wrought-iron plates . .	.. ..	2 2 0	1 2 6	0 7 6	0 7 7	0·7542
Bolts and nuts for ditto .	.. ..	0 3 2	0 7 8	0 3 2	0 11 6	0·7333
2 protectors, bolts, &c. .	.. ..	0 3 6	0 8 0	0 3 6	0 3 2	0·3333
2 buffer rams and shell . .	.. ..	2 2 22	0 16 2	0 6 2	0 1 11½	0·4062
2 spindle bolts and nuts. .	.. ..	0 1 6	0 4 11	0 3 5	0 1 1	0·2250
2 woodheads and springs .	.. ..	.. ..	1 10 2	1 10 2	0 9 7½	1·9896
2 sand-boxes and covers .	.. ..	2 1 20	0 14 7	0 5 7	0 1 8½	0·3646
2 ditto, seats, valve, and brass guides.	0 0 5	.. ..	0 5 0	0 3 6	0 1 1	0·2292
2 sand-box covers . . .	.. ..	.. ..	0 0 8	0 0 8	0 0 2½	0·0437
2 sets wrought ironwork. .	.. ..	0 2 10	0 5 11	0 2 11	0 19 8	1·1292
2 sandpipes and flanges, 9 ft.	.. ..	.. ..	0 7 10	0 7 10	0 0 10	0·4333
8 bolts and nuts for ditto .	.. ..	0 0 6	0 0 6	0 0 2	0 0 11	0·0542
2 sand-box packings. . .	.. ..	.. ..	0 0 6	0 0 6	0 1 0	0·0750
2 blow-off cocks and flanges	.. ..	.. ..	2 12 0	2 12 0	.. ..	2·6000
2 pipes, 10½ feet (3 ft.) . .	.. ..	.. ..	0 2 8	0 2 8	0 1 0	0·1833
8 studs and nuts	.. ..	0 0 3	0 0 3	0 0 1	0 1 0	0·0542
1 draw pin	.. ..	0 0 24	0 2 2	0 0 8	0 3 8	0·2167
						12·5125
1 small lubricator . . .	.. ..	.. ..	2 0 0	2 0 0	.. ..	2·0000
1 copper pipe	0 0 2	.. ..	0 3 3	0 2 9	0 0 4	0·1542
1 buffer plank chain . . .	.. ..	0 1 2	0 2 8	0 1 2	0 2 2	0·1667
1 shackle, &c.	.. ..	0 1 0	0 2 6	0 1 0	0 1 10	0·1417
						2·4625
Carried forward . .	112 1 3	559 2 17½	1484 3 1	1164 19 5¾	310 7 3	1475·3405

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.										
..	968·4592	1443·0036	1245·4381	625·0565	140·4266	726·3441	1385·8920	950·0879	357·3324	66·7935
30	0·3347	0·4987	0·4305	0·2159	0·0485	0·2511	0·4790	0·3284	0·1235	0·0231
30	0·3654	0·5443	0·4697	0·2356	0·0530	0·2739	0·5227	0·3583	0·1348	0·0252
30	0·2583	0·3849	0·3322	0·1666	0·0375	0·1938	0·3697	0·2534	0·0953	0·0178
30	0·3722	0·5546	0·4788	0·2401	0·0540	0·2792	0·5326	0·3651	0·1373	0·0257
30	0·2208	0·3291	0·2839	0·1424	0·0320	0·1656	0·3160	0·2166	0·0815	0·0152
30	0·3805	0·5670	0·4894	0·2454	0·0552	0·2854	0·5446	0·3733	0·1404	0·0262
30	0·2778	0·4138	0·3572	0·1791	0·0403	0·2083	0·3974	0·2725	0·1025	0·0192
30	0·3333	0·4967	0·4287	0·2150	0·0483	0·2500	0·4770	0·3270	0·1230	0·0230
30	1·3333	1·9866	1·7145	0·8600	0·1934	1·0000	1·9080	1·3080	0·4920	0·0920
30	1·0195	1·5190	1·3110	0·6576	0·1478	0·7646	1·4589	1·0001	0·3761	0·0703
30	0·2222	0·3311	0·2858	0·1433	0·0322	0·1666	0·3180	0·2180	0·0820	0·0153
..	5·1179	7·6258	6·5817	3·3010	0·7422	3·8385	7·3239	5·0207	1·8884	0·3530
7	1·7917	2·6696	2·3041	1·1556	0·2598	1·3437	2·5639	1·7577	0·6611	0·1236
7	0·5028	0·7492	0·6466	0·3243	0·0729	0·3771	0·7195	0·4933	0·1855	0·0347
7	0·4889	0·7284	0·6287	0·3153	0·0709	0·3667	0·6996	0·4796	0·1804	0·0337
7	0·2222	0·3311	0·2857	0·1433	0·0322	0·1666	0·3180	0·2180	0·0820	0·0153
7	0·2708	0·4035	0·3482	0·1747	0·0393	0·2031	0·3875	0·2657	0·1000	0·0187
7	0·1500	0·2235	0·1929	0·0967	0·0217	0·1125	0·2146	0·1472	0·0553	0·0103
7	1·3264	1·9763	1·7058	0·8555	0·1923	0·9948	1·8981	1·3012	0·4894	0·0915
7	0·2431	0·3622	0·3126	0·1568	0·0352	0·1823	0·3478	0·2385	0·0897	0·0168
7	0·1528	0·2277	0·1965	0·0986	0·0222	0·1146	0·2187	0·1500	0·0564	0·0105
7	0·0291	0·0433	0·0374	0·0187	0·0042	0·0219	0·0417	0·0286	0·0107	0·0020
7	0·7528	1·1217	0·9681	0·4856	0·1092	0·5646	1·0773	0·7385	0·2778	0·0519
7	0·2889	0·4304	0·3715	0·1863	0·0419	0·2166	0·4134	0·2834	0·1066	0·0200
7	0·0361	0·0538	0·0465	0·0233	0·0052	0·0271	0·0517	0·0354	0·0133	0·0025
7	0·0500	0·0745	0·0643	0·0322	0·0072	0·0375	0·0715	0·0490	0·0184	0·0034
7	1·7333	2·5827	2·2290	1·1180	0·2513	1·3000	2·4804	1·7005	0·6395	0·1196
7	0·1222	0·1820	0·1571	0·0788	0·0177	0·0917	0·1749	0·1199	0·0451	0·0084
7	0·0361	0·0538	0·0465	0·0233	0·0052	0·0271	0·0517	0·0354	0·0133	0·0025
7	0·1445	0·2151	0·1857	0·0931	0·0209	0·1083	0·2066	0·1416	0·0533	0·0100
..	8·3417	12·4288	10·7272	5·3801	1·2093	6·2562	11·9369	8·1835	3·0778	0·5754
17	1·3333	1·9866	1·7147	0·8600	0·1933	1·0000	1·9080	1·3081	0·4920	0·0920
17	0·1028	0·1532	0·1322	0·0663	0·0149	0·0770	0·1471	0·1008	0·0379	0·0071
17	0·1111	0·1657	0·1429	0·0719	0·0163	0·0834	0·1590	0·1090	0·0410	0·0077
17	0·0944	0·1409	0·1215	0·0609	0·0137	0·0709	0·1352	0·0927	0·0349	0·0065
..	1·6416	2·4464	2·1113	1·0591	0·2382	1·2313	2·3493	1·6106	0·6058	0·1133
..	983·5604	1465·5046	1264·8583	634·7967	142·6163	737·6701	1407·5021	964·9027	362·9044	67·8352

TABLE A.—ENGINE

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward	112 1 3	559 2 17½	1484 3 1	1164 19 5¾	310 7 3	1475·3405
1 plate	.. ..	0 0 4	0 0 4	0 0 1	0 0 2	0·0125
2 side chains	.. ..	0 1 26	0 4 10	0 3 4	0 6 2	0·4750
2 shackles, &c.	.. ..	0 1 4	0 2 10	0 1 4	0 2 6	0·1917
2 syphon hooks	.. ..	0 0 2	0 0 2	0 0 1	0 0 9	0·0417
						0·7209
1 tool-box and footboard	.. ..	.. ..	0 9 6	0 9 6	0 9 3	0·9375
6 belts for covering	.. ..	2 0 26	1 2 4	0 10 4	2 19 2½	3·4772
2 flanches	.. ..	0 0 7	0 0 7	0 0 3	0 1 5½	0·0854
2 stretchers	.. ..	0 0 16	0 1 5	0 0 7	0 3 4	0·1958
41 blocks	.. ..	0 3 7	0 8 2	0 3 8	1 1 0	1·2333
1 lamp iron	.. ..	0 0 2½	0 0 3	0 0 2	0 2 0	0·1083
1 ditto ditto	.. ..	0 0 7	0 0 7	0 0 3	0 1 6	0·0875
6 outside springs 2 inside springs	.. ..	11 2 7	9 5 0	5 16 0	1 14 8	7·5333
8 buckles for ditto	.. ..	1 0 24	0 19 5	0 13 5	0 10 10	1·2125
32 spring links	.. ..	2 3 20	1 9 3	0 12 9	3 4 6	3·8625
32 ditto pins	.. ..	0 1 20	0 4 3	0 2 9	0 17 8	1·0208
						19·7541
Weather board	.. ..	4 1 11	5 4 4	3 18 10	1 3 9	5·1292
Brass beading	0 2 1	.. ..	2 8 8	1 14 8	0 7 9	2·1208
Rivets put on	.. ..	0 0 6	0 1 2	0 0 10½	0 0 3	0·0562
5 roof stays and 2 bottom stays	.. ..	1 1 20	0 14 3	0 6 9	0 19 6	1·3125
2 columns	.. ..	1 1 15	0 13 10	0 6 4	1 5 5	1·5875
6 brass nuts for columns	.. ..	.. ..	0 6 0	0 6 0	1 10 3	1·8125
2 spectacle eyes and screws	.. ..	.. ..	0 13 0	0 13 0	3 5 6	3·9250
2 pieces plate glass	.. ..	.. ..	0 2 10	0 2 10	0 14 3	0·8542
						16·7979
India rubber pipe	.. ..	.. ..	0 5 3	0 5 3	.. ..	0·2625
Total	112 3 4	587 0 18	1509 1 4	1181 8 6¾	331 8 11	1512·8579

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Present Value. New.	Good.	Indif.	Bad.
years.	..	983·5604	1465·5046	1264·8583	634·7967	142·6163	737·6701	1407·5021	964·9027	362·9044	67·8352
17	0·0083	0·0124	0·0107	0·0054	0·0010	0·0062	0·0119	0·0082	0·0031	0·0006
17	0·3167	0·4716	0·4072	0·2040	0·0459	0·2375	0·4532	0·3107	0·1168	0·0218
17	0·1278	0·1903	0·1643	0·0824	0·0185	0·0959	0·1829	0·1254	0·0472	0·0088
17	0·0278	0·0414	0·0357	0·0179	0·0040	0·0208	0·0398	0·0273	0·0103	0·0019
..	0·4806	0·7157	0·6179	0·3097	0·0694	0·3604	0·6878	0·4716	0·1774	0·0331
15	0·6250	0·9313	0·8037	0·4031	0·0906	0·4687	0·8944	0·6131	0·2306	0·0401
15	2·3181	3·4539	2·9811	1·4952	0·3362	1·7386	3·3172	2·2741	0·8553	0·1599
15	0·0570	0·0849	0·0732	0·0367	0·0082	0·0427	0·0815	0·0558	0·0210	0·0039
15	0·1305	0·1945	0·1679	0·0842	0·0189	0·0979	0·1868	0·1281	0·0482	0·0090
15	0·8222	1·2252	1·0574	0·5303	0·1193	0·6167	1·1766	0·8066	0·3034	0·0567
15	0·0722	0·1076	0·0928	0·0466	0·0105	0·0541	0·1033	0·0708	0·0266	0·0050
15	0·0583	0·0869	0·0750	0·0376	0·0084	0·0438	0·0835	0·0572	0·0215	0·0040
15	5·0222	7·4832	6·4585	3·2393	0·7283	3·7667	1·1869	4·9269	1·8530	0·3464
15	0·8084	1·2044	1·0395	0·5214	0·1173	0·6063	1·1567	0·7930	0·2982	0·0577
15	2·5750	3·8367	3·3115	1·6609	0·3734	1·9312	3·6849	2·5261	0·9501	0·1776
15	0·6805	1·0140	0·8752	0·4390	0·0987	0·5104	0·9739	0·6676	0·2511	0·0469
..	13·1694	19·6226	16·9358	8·4943	1·9098	9·8771	18·8457	12·9193	4·8590	0·9072
30	3·4195	5·0951	4·3975	2·2056	0·4958	2·5646	4·8934	3·3546	1·2617	0·2358
30	1·4139	2·1067	1·8183	0·9119	0·2051	1·0604	2·0233	1·3870	0·5217	0·0975
30	0·0375	0·0559	0·0482	0·0243	0·0054	0·0281	0·0536	0·0367	0·0138	0·0026
30	0·8750	1·3037	1·1253	0·5644	0·1269	0·6562	1·2521	0·8584	0·3228	0·0603
30	1·0583	1·5769	1·3610	0·6826	0·1535	0·7938	1·5145	1·0382	0·3905	0·0730
30	1·2083	1·8004	1·5539	0·7794	0·1752	0·9062	1·7292	1·1854	0·4458	0·0833
30	2·6167	3·8989	3·3651	1·6878	0·3794	1·9625	3·7445	2·5670	0·9655	0·1805
30	0·5694	0·8485	0·7324	0·3673	0·0826	0·4271	0·8149	0·5586	0·2101	0·0393
..	11·1980	16·6861	14·4017	7·2233	1·6239	8·3989	16·0255	10·9859	4·1319	0·7723
0½	0·1750	0·2608	0·2250	0·1129	0·0254	0·1313	0·2504	0·1717	0·0646	0·0121
..	1008·5844	1502·7898	1297·0387	650·9369	146·2448	756·4378	1443·3115	989·4512	372·1373	69·5599

TABLE B.[1]—TENDER VALUATION (based upon Mr. WEBB's data).

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.	Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Variable Wear. Present Value. Good.	Variable Wear. Present Value. Indif.	Variable Wear. Present Value. Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Uniform Wear. Present Value. Good.	Uniform Wear. Present Value. Indif.	Uniform Wear. Present Value. Bad.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.	years										
3 axles (Cooper's) turned and planed	.. ..	14 2 16	17 11 5	13 18 11	0 13 0	14·5958	30	9·7305	14·4985	12·5135	6·2762	1·4109	7·2979	13·9823	9·6036	3·5326	0·6135
6 wheels centres, 3 ft. 6 in.	.. ..	31 0 14	45 10 5	37 15 5	2 4 9	40·0083	30	26·6722	39·7416	34·3004	17·2036	3·8675	20·0042	38·3267	26·3243	9·6832	1·6815
24 keys for ditto	.. ..	0 2 22	0 6 11½	0 4 5½	0 8 0	0·6229	30	0·4153	0·6187	0·5340	0·2678	0·0602	0·3114	0·5967	0·4098	0·1508	0·0262
						55·2270	..	36·8180	54·8588	47·3479	23·7476	5·3386	27·6135	52·9057	36·3377	13·3666	2·3212
6 tires, 3 ft. 6 in. and 2¼	.. ..	28 2 24	42 3 5½	33 12 5½	1 10 4	35·1396	3	23·4264	34·9053	30·1263	15·1100	3·3968	17·5698	33·6627	23·1208	8·5049	1·4769
Bolts and nuts for ditto	.. ..	0 0 23	0 2 1	0 0 10½	0 3 8	0·2271	3	0·1514	0·2256	0·1947	0·0976	0·0219	0·1135	0·2176	0·1494	0·0550	0·0095
						35·3667	..	23·5778	35·1309	30·3210	15·2076	3·4187	17·6833	33·8803	23·2702	8·5599	1·4864
6 axle-boxes and caps	.. ..	5 3 7	1 14 10½	0 11 10½	0 2 8	0·7271	10	0·4847	0·7223	0·6234	0·3127	0·0703	0·3635	0·6965	0·4784	0·1760	0·0306
6 brasses for ditto	1 0 8	.. ..	6 0 0	4 10 0	1 0 2	5·5083	10	3·6722	5·4716	4·7225	2·3686	0·5325	2·7542	5·2768	3·6243	1·3333	0·2315
6 pins for ditto	.. ..	0 0 2	0 0 2	0 0 1	.. ..	0·0042	10	0·0028	0·0041	0·0036	0·0018	0·0004	0·0021	0·0040	0·0028	0·0010	0·0002
						6·2396	..	4·1597	6·1980	5·3495	2·6831	0·6032	3·1198	5·9773	4·1055	1·5103	0·2623
6 springs	.. ..	5 3 8	4 13 2	2 18 8	0 15 0	3·6833	15	2·4555	3·6587	3·1578	1·5838	0·3560	1·8416	3·5285	2·4235	0·8915	0·1548
6 buckles	.. ..	0 2 18	0 10 7	0 8 1	0 8 9	0·8417	15	0·5612	0·8361	0·7216	0·3619	0·0814	0·4209	0·8063	0·5538	0·2037	0·0354
6 spring-pins	.. ..	0 1 0	0 2 6	0 1 3	0 2 8	0·1958	15	0·1305	0·1945	0·1679	0·0842	0·0189	0·0979	0·1876	0·1288	0·0474	0·0082
						4·7208	..	3·1472	4·6893	4·0473	2·0299	0·4563	2·3604	4·5224	3·1061	1·1426	0·1984
24 spring links and pins	.. ..	1 1 9	0 13 4	0 7 1	1 9 9	1·8416	30	1·2277	1·8293	1·5789	0·7919	0·1780	0·9208	1·7642	1·2117	0·4457	0·0774
4 frame plates	.. ..	29 1 4	29 5 8½	21 19 5½	1 15 2	23·7313	30	15·8209	23·5731	20·3456	10·2045	2·2940	11·8656	22·7339	15·6145	5·7437	0·9974
12 horn blocks	.. ..	6 0 24	1 17 3	0 19 3	0 9 0	1·4125	30	0·9417	1·4032	1·2110	0·6075	0·1366	0·7063	1·3531	0·9294	0·3419	0·0594
6 distance pieces	.. ..	3 2 22	1 2 2	0 4 8	0 2 9	0·3708	30	0·2472	0·3683	0·3179	0·1594	0·0358	0·1854	0·3552	0·2440	0·0897	0·0156
						27·3562	..	18·2375	27·1739	23·4534	11·7633	2·6444	13·6781	26·2064	17·9996	6·6210	1·1498
4 bottom stays	.. ..	2 1 16	1 18 3	1 7 0	2 1 0	3·4000	30	2·2667	3·3773	2·9149	1·4620	0·3287	1·7000	3·2571	2·2371	0·8229	0·1429
12 axle-box stays	.. ..	0 2 22	0 7 0	0 4 6	0 10 9	0·7625	30	0·5083	0·7574	0·6537	0·3279	0·0737	0·3813	0·7304	0·5017	0·1845	0·0320
96 bolts and nuts, 5 ft. 8 in.	.. ..	0 3 10	0 8 5	0 4 8	0 9 2	0·6916	30	0·4611	0·6870	0·5929	0·2974	0·0668	0·3458	0·6625	0·4550	0·1674	0·0291
						4·8541	..	3·2361	4·8217	4·1615	2·0873	0·4692	2·4271	4·6500	3·1938	1·1748	0·2040
2 pieces of oak	.. ..	.. ..	2 0 0	2 0 0	0 18 0	2·9000	15	1·9633	2·8806	2·4863	1·2170	0·2803	1·4500	2·7781	1·9081	0·7019	0·1219
Carried forward	1 0 8	132 1 17	156 7 9	121 8 8½	15 4 7	136·6644	..	91·1096	135·7532	117·1669	58·7658	13·2107	68·3322	130·9202	89·9210	33·0771	5·7440

[1] A summary of this Table is given on page 187.

TABLE B.—TENDER

NAME.	Brass, Copper, &c.	Cast and Wrought Iron, &c.	Cost of Materials.						Cost of Labour.			Net Cost, including Labour.
	Gross Weight.	Gross Weight.	Gross.			Net.						
	cwt. qrs. lbs.	cwt. qrs. lbs.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£. dec.
Brought forward . .	1 0 8	132 1 17	156	7	9	121	8	8½	15	4	7	136·6644
104 bolts for frames . . .	.. ..	1 1 18	0	14	1	0	7	10	0	14	10	1·1333
4 steps	.. ..	0 1 12	0	3	7	0	2	4	0	4	8	0·3500
Men's time fitting above .	.. ..	.. ..	..	..		..	..		3	10	0	3·5000
Iron plates (inside frame) .	.. ..	12 2 15	9	9	6	6	7	0	4	13	10	11·0417
Ditto ditto . .	.. ..	3 1 7	2	9	8	1	13	5	1	4	8	2·9042
Angle iron for ditto . . .	.. ..	12 0 0	13	4	0	10	4	0	7	10	10	17·7417
Rivets for ditto	.. ..	1 1 0	1	6	3	1	0	0	0	14	9	1·7375
Tension bolts and cotters .	.. ..	0 1 26	0	4	10	0	3	7½	0	8	4	0·5979
2 sockets for ditto . . .	.. ..	0 0 19	0	1	8	0	0	10	0	1	6	0·1166
1 draw-bolt, nuts, and plates	.. ..	0 3 0	0	12	0	0	8	3	0	15	9	1·2000
1 buffer-spring	.. ..	2 3 14	2	6	0	1	9	6	0	9	8	1·9583
1 buckle for ditto . . .	.. ..	0 1 9	0	5	3	0	4	0	0	7	0	0·5500
2 buffer shoes	.. ..	0 0 22	0	3	1½	0	2	2	0	4	3	0·3208
2 buffer guides	.. ..	0 2 8	0	3	5	0	1	11	0	1	6	0·1708
2 buffer blocks	.. ..	1 0 2	0	6	1	0	3	1	0	0	2	0·1625
2 intermediate buffers . .	.. ..	1 2 22	0	10	2	0	5	8	0	6	2	0·5916
												44·0769
2 trailing buffers . . .	.. ..	1 0 4	0	16	7	0	11	7	0	14	0	1·2792
2 wood-heads for ditto . .	.. ..	.. ..	0	1	2	0	1	2	0	0	10	0·1000
2 buffer blocks	.. ..	.. ..	0	1	0	0	1	0	0	0	10	0·0916
2 springs for ditto . . .	.. ..	.. ..	0	4	0	0	4	0	0	2	5	0·3208
Bolts and nuts for ditto .	.. ..	0 1 6	0	3	0	0	1	9	0	1	1	0·1417
2 hoops for buffers . . .	.. ..	0 0 12	0	1	1	0	0	6½	0	1	6	0·1021
2 angle irons for ditto . .	.. ..	0 1 3	0	2	9	0	1	6	..	..		0·0750
												2·1104
1 oak plank	.. ..	.. ..	0	11	8	0	11	8	0	15	0	1·3333
2 plates for ditto . . .	.. ..	0 3 24	0	9	7½	0	5	10½	0	4	0	0·4938
Bolts and nuts for ditto .	.. ..	0 1 8	0	3	2½	0	1	11½	0	5	6	0·3729
1 shackle chain and hook .	.. ..	0 1 17	0	4	0	0	2	9	0	2	1	0·2416
1 drag pin	.. ..	0 0 26	0	2	4	0	1	2	0	3	9	0·2458
2 eyes, shackles, and bolts .	.. ..	0 1 25	0	4	9	0	3	6	0	8	6	0·6000
2 coupling-boxes . . .	.. ..	0 0 21	0	1	1½	0	0	2	0	0	6	0·0833
1 front footplate . . .	.. ..	1 1 21	0	15	5	0	9	2	0	0	7	0·4875
2 side footplates	.. ..	1 2 10	0	17	1	0	9	7	0	0	8	0·5125
3 backplates	.. ..	4 1 21	3	6	7	2	5	4	0	15	4	3·0333
Angle iron for ditto . . .	.. ..	8 0 12	8	18	4	6	18	4	2	6	9	9·2542
Iron rivets for ditto . .	.. ..	1 0 0	0	16	0	1	1	0	0	5	5	1·0708
												16·3457
Carried forward . .	1 0 8	192 1 9	206	12	1	157	9	4½	43	1	3	200·5301

VALUATION—*continued.*

Life.	Variable Wear.					Uniform Wear.				
	Standard of Efficiency.	Present Value.				Standard of Efficiency.	Present Value.			
		New.	Good.	Indif.	Bad.		New.	Good.	Indif.	Bad.
years.										
..	91·1096	135·7532	117·1669	58·7658	13·2107	68·3322	130·9202	89·9210	33·0771	5·7440
30	0·7555	1·1257	0·9716	0·4873	0·1096	0·5666	1·0857	0·7457	0·2743	0·0476
30	0·2333	0·3477	0·3001	0·1505	0·0338	0·1750	0·3353	0·2303	0·0847	0·0147
..	2·3333	3·4766	3·0007	1·5050	0·3383	1·7500	3·3529	2·3029	0·8471	0·1471
30	7·3611	10·9682	9·4664	4·7479	1·0674	5·5208	10·5776	7·2651	2·6721	0·4611
30	1·9361	2·8848	2·4899	1·2489	0·2807	1·4521	2·7821	1·9108	0·7029	0·1221
30	11·8278	17·6234	15·2105	7·6289	1·7150	8·8709	16·9960	11·6735	4·2940	0·7457
30	1·1583	1·7259	1·4896	0·7471	0·1680	0·8687	1·6645	1·1432	0·4205	0·0730
30	0·3986	0·5939	0·5126	0·2571	0·0578	0·2990	0·5728	0·3934	0·1447	0·0251
30	0·0777	0·1159	0·1000	0·0501	0·0113	0·0583	0·1117	0·0767	0·0282	0·0049
30	0·8000	1·1920	1·0288	0·5160	0·1160	0·6000	1·1496	0·7896	0·2904	0·0504
30	1·3056	1·9453	1·6789	0·8421	0·1893	0·9791	1·8760	1·2885	0·4740	0·0823
30	0·3667	0·5464	0·4715	0·2365	0·0532	0·2750	0·5269	0·3619	0·1331	0·0231
30	0·2139	0·3187	0·2750	0·1379	0·0310	0·1604	0·3073	0·2111	0·0776	0·0135
30	0·1139	0·1697	0·1464	0·0734	0·0165	0·0854	0·1636	0·1124	0·0413	0·0072
30	0·1084	0·1614	0·1393	0·0699	0·0157	0·0813	0·1557	0·1069	0·0393	0·0068
30	0·3944	0·5876	0·5073	0·2544	0·0573	0·2958	0·5667	0·3893	0·1432	0·0249
..	29·3846	43·7832	37·7886	18·9530	4·2609	22·0384	42·2244	29·0013	10·6677	1·8525
15	0·8528	1·2707	1·0967	0·5501	0·1237	0·6396	1·2254	0·8417	0·3096	0·0538
15	0·0666	0·0993	0·0857	0·0430	0·0097	0·0500	0·0958	0·0658	0·0242	0·0042
15	0·0611	0·0910	0·0785	0·0394	0·0088	0·0458	0·0877	0·0603	0·0222	0·0038
15	0·2139	0·3186	0·2750	0·1379	0·0310	0·1604	0·3073	0·2111	0·0776	0·0135
15	0·0945	0·1408	0·1215	0·0610	0·0137	0·0708	0·1357	0·0932	0·0343	0·0060
15	0·0681	0·1014	0·0875	0·0439	0·0099	0·0511	0·0978	0·0672	0·0247	0·0043
15	0·0500	0·0745	0·0643	0·0322	0·0072	0·0375	0·0718	0·0493	0·0181	0·0031
..	1·4070	2·0963	1·8092	0·9075	0·2040	1·0552	2·0215	1·3886	0·5107	0·0887
5	0·8889	1·3244	1·1431	0·5733	0·1289	0·6666	1·2773	0·8773	0·3226	0·0560
30	0·3292	0·4905	0·4234	0·2123	0·0477	0·2469	0·4730	0·3249	0·1195	0·0207
30	0·2486	0·3704	0·3197	0·1603	0·0360	0·1864	0·3572	0·2454	0·0902	0·0157
30	0·1610	0·2400	0·2071	0·1039	0·0233	0·1208	0·2314	0·1590	0·0585	0·0101
30	0·1639	0·2442	0·2107	0·1057	0·0238	0·1229	0·2355	0·1617	0·0595	0·0103
30	0·4000	0·5960	0·5145	0·2580	0·0580	0·3000	0·5748	0·3948	0·1452	0·0252
30	0·0222	0·0331	0·0285	0·0143	0·0032	0·0167	0·0319	0·0219	0·0081	0·0014
30	0·3250	0·1843	0·4180	0·2096	0·0472	0·2437	0·4670	0·3208	0·1180	0·0205
30	0·3417	0·5090	0·4393	0·2204	0·0495	0·2563	0·4910	0·3372	0·1240	0·0215
30	2·0222	3·0132	2·6005	1·3043	0·2933	1·5166	2·9058	1·9958	0·7341	0·1275
30	6·1694	9·1924	7·9341	3·9794	0·8946	4·6271	8·8652	6·0890	2·2398	0·3890
30	0·7139	1·0637	0·9180	0·4604	0·1035	0·5354	1·0258	0·7045	0·2592	0·0450
..	10·8971	16·2368	14·0138	7·0286	1·5801	8·1728	15·6586	10·7550	3·9561	0·6869
..	133·6872	199·1939	171·9216	86·2282	19·3846	100·2652	192·1020	131·9432	48·5342	8·4281

TABLE B.—TENDER

NAME.	Brass, Copper, &c. Gross Weight.	Cast and Wrought Iron, &c. Gross Weight.	Cost of Materials. Gross.	Cost of Materials. Net.	Cost of Labour.	Net Cost, including Labour.
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	1 0 8	192 1 9	206 12 1	157 9 4½	43 1 3	200·5307
1 break, screw, nut, and handle.	.. ..	0 2 14	0 10 0	0 7 6	0 15 6	1·1500
1 break shaft	.. ..	1 3 0	1 8 0	0 19 3	1 2 6	2·0875
6 break hangers. . . .	.. ..	2 0 0	1 12 0	1 2 0	0 11 6	1·6750
6 break rods and pins . .	.. ..	2 0 24	1 2 1½	0 12 1½	1 10 8	2·1396
2 break stays, and 6 pins and rollers	.. ..	0 1 17	0 4 0	0 2 9	0 5 2	0·3958
1 break column	.. ..	0 2 15	0 3 9½	0 1 9½	0 1 8	0·1729
6 brackets for brake hangers	.. ..	1 2 26	0 10 4½	0 4 4½	0 3 2	0·3771
4 break shaft brushes . .	.. ..	0 0 18	0 0 11½	0 0 4	0 3 0	0·1667
1 brass bush and flanch .	0 0 6	.. ..	0 6 0	0 4 6	0 0 9	0·2625
Valve rods	.. ..	0 0 11	0 1 0	0 0 6	0 2 10	0·1666
2 valve seatings	.. ..	0 1 12	0 2 1½	0 1 1½	0 3 2	0·2146
2 brass valves and seats .	0 0 10	.. ..	0 10 0	0 7 6	0 1 8	0·4583
2 wheels	.. ..	0 0 6	0 0 4	0 0 1½	.. ..	0·0063
2 cages	.. ..	.. ..	0 5 0	0 5 0	.. ..	0·2500
4 feed-pipe flanches. . .	0 0 13	.. ..	0 13 0	0 9 9	0 0 8	0·5208
Bolts for feed pipes. . .	.. ..	0 0 12	0 1 1	0 0 6½	0 1 4	0·0937
2 copper feed pipes . . .	0 0 26	.. ..	1 13 7	1 7 1	0 2 6	1·4792
2 stays for ditto	.. ..	0 1 20	0 4 3	0 3 0	0 2 3	0·2625
2 clips for ditto	.. ..	0 0 7	0 0 7½	0 0 3½	0 1 1	0·0687
2 metals for ditto . . .	0 0 8	.. ..	0 8 0	0 6 0	0 1 1	0·3542
1 number-plate	0 0 4	.. ..	0 4 0	0 3 0	0 0 6	0·1750
1 lamp iron	.. ..	0 0 12	0 1 1	0 0 6½	0 0 1	0·0312
						11·3582
2 handrail pillars and knobs	0 1 0	.. ..	1 8 0	1 1 0	0 1 6	1·1250
3 iron plates, inside of tank	.. ..	10 0 14	5 8 10	2 18 10	2 14 11	5·6875
4 ditto, outside of ditto. .	.. ..	9 1 4	4 19 10	2 13 7	2 10 0	5·1792
4 iron plates, tops and bottoms	.. ..	4 0 10	2 3 11½	1 3 11½	1 2 4	2·3146
4 ditto ditto	.. ..	11 1 24	6 3 3	3 7 0	3 2 7	6·4792
1 ditto, back.	.. ..	1 1 1	0 13 6	0 7 3	0 6 9	0·7000
7 ditto ditto	.. ..	3 0 14	1 13 7	0 18 7	0 17 4	1·7958
1 ditto ditto, manhole . .	.. ..	0 1 18	0 9 0	0 7 9	0 7 3	0·7500
1 ditto	.. ..	0 0 14	0 2 9	0 2 1½	0 2 0	0·2063
2 ditto, corner of tank .	.. ..	0 0 19	0 3 9	0 2 11	0 2 9	0·2833
Angle iron for ditto. . .	.. ..	7 3 14	8 13 3	6 14 6	6 5 6	13·0000
Iron rivets for ditto. . .	.. ..	2 3 25	3 2 5	2 8 8	2 5 5	4·7042
Bar iron for stays . . .	.. ..	1 0 0	0 12 6	0 7 6	0 7 0	0·7250
½ round iron	.. ..	1 0 10	0 19 7	0 14 7	0 13 7	1·4083
						44·3584
Carried forward . .	1 3 19	256 0 6	253 7 7½	187 16 8½	69 11 3	257·3973

VALUATION—*continued.*

Life.	Variable Wear. Standard of Efficiency.	Variable Wear. Present Value. New.	Good.	Indif.	Bad.	Uniform Wear. Standard of Efficiency.	Uniform Wear. Present Value. New.	Good.	Indif.	Bad.
years.										
..	133·6872	199·1939	171·9216	86·2282	19·3846	100·2652	192·1020	131·9432	48·5342	8·4281
15	0·7667	1·1423	0·9859	0·4945	0·1112	0·5750	1·1017	0·7567	0·2783	0·0483
30	1·3917	2·0736	1·7897	0·8976	0·2018	1·0437	1·9998	1·3735	0·5052	0·0877
30	1·1167	1·6638	1·4360	0·7202	0·1619	0·8375	1·6046	1·1021	0·4054	0·0704
30	1·4264	2·1253	1·8343	0·9200	0·2068	1·0698	2·0497	1·4078	0·5178	0·0899
30	0·2639	0·3932	0·3393	0·1702	0·0383	0·1979	0 3792	0·2604	0·0958	0·0166
30	0·1152	0·1717	0·1482	0·0743	0·0167	0·0864	0·1656	0·1138	0·0418	0·0073
30	0·2514	0·3746	0·3233	0·1622	0·0364	0·1885	0·3612	0·2481	0·0913	0·0158
30	0·1111	0·1656	0·1429	0·0717	0·0161	0·0834	0·1597	0·1097	0·0403	0·0070
30	0·1750	0·2607	0·2250	0·1129	0·0254	0·1312	0·2515	0·1727	0·0635	0·0110
30	0·1110	0·1655	0·1428	0·0716	0·0161	0·0833	0·1596	0·1096	0·0403	0·0070
30	0·1431	0·2132	0·1840	0·0923	0·0207	0·1073	0·2056	0·1412	0·0519	0·0090
30	0·3055	0·4553	0·3929	0·1971	0·0443	0·2292	0·4390	0·3016	0·1109	0·0193
30	0·0042	0·0063	0·0054	0·0027	0·0006	0·0031	0·0060	0·0041	0·0015	0·0003
30	0·1667	0·2483	0·2144	0·1075	0·0242	0·1250	0·2394	0·1645	0·0605	0·0105
30	0·3472	0·5173	0·4465	0·2239	0·0503	0·2604	0·4989	0·3427	0·1260	0·0219
30	0·0625	0·0931	0·0804	0·0403	0·0090	0·0468	0·0898	0·0616	0·0227	0·0039
30	0·9861	1,4693	1·2683	0·6361	0·1431	0·7396	1·4170	0·9733	0·3580	0·0622
30	0·1750	0·2607	0·2251	0·1129	0·0254	0·1312	0·2515	0·1727	0·0635	0·0110
30	0·0458	0·0683	0·0589	0·0295	0·0066	0·0344	0·0658	0·0452	0·0166	0·0029
30	0·2361	0·3519	0·3037	0·1523	0·0343	0·1771	0·3393	0·2330	0·0857	0·0149
30	0·1167	0·1738	0·1500	0·0753	0·0169	0·0875	0·1676	0·1151	0·0424	0·0073
30	0·0208	0·0310	0·0267	0·0134	0·0030	0·0156	0·0299	0·0205	0·0075	0·0013
..	7·5721	11·2825	9·7378	4·8840	1·0979	5·6789	10·8807	7·4732	2·7486	0·4772
30	0·7500	1·1175	0·9645	0·4837	0·1088	0·5625	1·0777	0·7402	0·2723	0·0473
30	3·7917	5·6496	4·8761	2·4456	0·5498	2·8437	5·4484	3·7422	1·3765	0·2390
30	3·4528	5·1447	4·4403	2·2270	0·5007	2·5896	4·9615	3·4078	1·2535	0·2177
30	1·5430	2·2992	1·9844	0·9953	0·2237	1·1573	2·2173	1·5229	0·5602	0·0973
30	4·3194	6·4361	5·5548	2·7861	0·6263	3·2396	6·2069	4·2631	1·5682	0·2723
30	0·4667	0·6953	0·6001	0·3010	0·0677	0·3500	0·6706	0·4606	0·1694	0·0294
30	1·1972	1·7838	1·5396	0·7722	0·1736	0·8979	1·7203	1·1816	0·4346	0·0755
30	0·5000	0·7450	0·6430	0·3225	0·0725	0·3750	0·7185	0·4935	0·1815	0·0315
30	0·1375	0·2049	0·1769	0·0886	0·0199	0·1031	0·1976	0·1357	0·0499	0·0087
30	0·1889	0·2814	0,2429	0·1218	0·0274	0·1417	0·2714	0·1864	0·0686	0·0119
30	8·6667	12·9133	11·1453	5·5900	1·2567	6·5000	12·4536	8·5536	3·1464	0·5464
30	3·1361	4·6728	4·0330	2·0228	0·4547	2·3521	4·5065	3·0952	1·1386	0·1977
30	0·4833	0·7202	0·6216	0·3119	0·0701	0·3625	0·6945	0·4770	0·1755	0·0305
30	0·9389	1·3989	1·2074	0·6056	0·1361	0·7041	1·3491	0·9266	0·3408	0·0592
..	29·5722	44·0627	38·0299	19·0741	4·2880	22·1791	42·4939	29·1864	10·7360	1·8644
..	171·5982	255·6814	220·6752	110·6808	24·8817	128·6982	246·5783	169·3595	62·2971	10·8180

TABLE B.—TENDER

NAME.	Brass, Copper, &c.	Cast and Wrought Iron, &c.	Cost of Materials.		Cost of Labour.	Net Cost, including Labour.
	Gross Weight	Gross Weight.	Gross.	Net.		
	cwt. qrs. lbs.	cwt. qrs. lbs.	£. s. d.	£. s. d.	£. s. d.	£. dec.
Brought forward . .	1 3 19	256 0 6	253 7 7½	187 16 8½	69 11 3	257·3973
Wood bottom and packing for tanks	.. ..	.. ..	0 13 7	0 13 7	0 10 10	1·2209
Nails and screws . . .	.. ..	.. ..	0 6 6	0 6 6	0 5 2	0·5833
						1·8042
Paint, &c.	.. ..	.. ..	2 1 6	2 1 6	2 9 10	4·5666
Erectors' time	.. ..	.. ..	.. ..	.. ..	11 0 0	11·0000
6 break blocks	.. ..	.. ..	0 3 6	0 3 6	0 3 0	0·3250
2 rose packings	.. ..	.. ..	0 1 0	0 1 0	0 1 0	0·1000
						0·4250
Total	1 3 19	256 0 6	256 13 8½	191 2 9½	84 1 1	275·1931

SUMMARY OF TABLE A.—ENGINE VALUATION.

Total Net Cost of Engine . . . . . £. dec. 1,512·89

	Variable Wear.		Uniform Wear.	
	Net Value.	Standard of Efficiency in each Period.[1]	Net Value.	Standard of Efficiency in each Period.[1]
	£. dec.	£. dec.	£. dec.	£. dec.
Net value of a New Engine .	1,502·79	150·28	1,443·31	132·73
„ „ „ Good „ .	1,297·04	648·52	989·45	502·68
„ „ „ Indif. „ .	650·54	195·15	372·14	111·62
„ „ „ Bad „ .	146·24	14·62	69·56	6·40
Standard average condition of efficiency of one of a series of Engines	.. ..	1,008·57	.. ..	756·43

[1] See page 141, "Normal Dilapidation."

VALUATION—*continued*.

Life.	Variable Wear.					Uniform Wear.				
	Standard of Efficiency.	Present Value.				Standard of Efficiency.	Present Value.			
		New.	Good.	Indif.	Bad.		New.	Good.	Indif.	Bad.
years.										
..	171·5982	255·6814	220·6752	110·6808	24·8817	128·6982	246·5783	169·3595	62·2971	10·8180
10	0·8139	1·2127	1·0467	0·5250	0·1180	0·6104	1·1696	0·8033	0·2955	0·0513
10	0·3889	0·5794	0·5001	0·2508	0·0564	0·2917	0·5588	0·3838	0·1412	0·0245
..	1·2028	1·7921	1·5468	0·7758	0·1744	0·9021	1·7284	1·1871	0·4367	0·0758
3	3·0444	4·5362	3·9152	1·9637	0·4415	2·2833	4·3747	3·0047	1·1052	0·1919
30	7·3334	10·9267	9·4306	4·7300	1·0633	5·5000	10·5377	7·2377	2·6623	0·4623
0½	0·2167	0·3228	0·2786	0·1397	0·0314	0·1625	0·3113	0·2138	0·0787	0·0137
0½	0·0666	0·0993	0·0857	0·0430	0·0097	0·0500	0·0958	0·0658	0·0242	0·0042
..	0·2833	0·4221	0·3643	0·1827	0·0411	0·2125	0·4071	0·2796	0·1029	0·0179
..	183·4621	273·3585	235·9321	118·3330	26·6020	137·5961	263·6262	181·0686	66·6042	11·5659

SUMMARY OF TABLE B.—TENDER VALUATION.

Total Net Cost of Tender . . . . . £. dec. 275·19

	Variable Wear.		Uniform Wear.	
	Net Value.	Standard of Efficiency in each Period.[1]	Net Value.	Standard of Efficiency in each Period.[1]
	£. dec.	£. dec.	£. dec.	£. dec.
Net value of a New Tender .	273·36	27·34	263·63	22·96
„ „ „ Good „ .	235·93	117·97	181·07	92·62
„ „ „ Indif. „ .	118·33	35·49	66·60	20·97
„ „ „ Bad „ .	26·60	2·66	11·57	1·05
Standard average condition of efficiency of one of a series of Tenders	.. ..	183·46	.. ..	137·60

[1] See page 144, "Normal Dilapidation."

TABLE D *d*.

LOCOMOTIVE VALUATION.

Life in Train Miles.	Life in Years.	——	Net Cost.	Number of Renewals in Period of Longest Life.	Total Net Cost in Period of Longest Life.
	months.		£. dec.		£. dec.
10,000	6	India-rubber pipe . . .	0·2625	60	15·7500
	years.				
40,000	2	Slide valves	5·3417	15	80·1254
80,000	4	Painting	8·2333	$7\frac{1}{2}$	61·7504
100,000	5	Crank axles and brass tubes	183·6125	6	1,101·6750
140,000	7	Tires and framing . . .	90·7646	$4\frac{2}{7}$	388·9914
160,000	8	Chimney, &c.	4·8688	$3\frac{3}{4}$	18·2579
180,000	9	Set of gland bushes . .	5·3917	$3\frac{1}{3}$	17·9721
200,000	10	Axle-boxes, piston-rods, boiler-plates and lagging	463·5813	3	1,390·7439
240,000	12	Cylinder covers	39·4458	$2\frac{1}{2}$	98·6143
300,000	15	Eccentric straps, coupling-rod ends, springs, &c. .	116·2487	2	232·4974
340,000	17	Lubricator, copper-pipe, and buffer planks . .	3·6459	$1\frac{14}{17}$	6·4340
400,000	20	Two plain axles, 6 wheels and keys, outside cranks, connecting-rods, &c., feed-pipes, cocks, and injector	237·5730	$1\frac{1}{2}$	356·3609
500,000	25	Fire-box brackets, syphon caps, &c., &c. . . .	25·9686	$1\frac{1}{5}$	31·1623
600,000	30	Slide-box brackets, copper pipes, boiler fittings, horn plates, framing and cost of erection	268·6147	1	268·6147
			£1,453·5531		£4,068·9497

$$\frac{4,068\cdot9497}{30} = 135\cdot6316 \text{ average cost of repairs per annum.}$$

$$\frac{1453\cdot5531}{135\cdot6316} = 10\cdot717 \text{ years' mean life.}$$

TABLE E *e*.

TENDER VALUATION.

Life in Train Miles.	Life in Years.	——	Net Cost.	Number of Renewals in Period of Longest Life.	Total Net Cost in Period of Longest Life.
	months.		£. dec.		£. dec.
10,000	6	Six break blocks and rose packings, &c. . . .	0·4250	60	25·5000
	years.				
60,000	3	Six tires, and bolts, and nuts, painting . . .	39·9480	10	399·4800
100,000	5	Oak plank	1·3333	6	8·0000
200,000	10	Six axle-boxes and brasses, wood bottom and packing for tank	8·4749	3	25·4247
300,000	15	Springs, trailing buffers, buffer blocks and springs, &c.	10·9521	2	21·9012
600,000	30	Axles and wheel-centres, spring links, frame-plates, horn blocks, plates, and angle-irons to framing coupling-boxes, foot-plates, break shaft, and details, valves rods and feed-pipes, handrails, &c., erector's time	219·7521	1	219·7521
		£	280·8854	£	700·0610

$$\frac{700\cdot0610}{30} = £23\cdot3353 \text{ average cost of repairs per annum.}$$

$$\frac{280\cdot8854}{23\ 3353} = 12\cdot04 \text{ years' mean life.}$$

TABLE 1*a*.

VALUATION of ENGINE, based on the assumption of uniform wear (See note, p. 150).

Total Net Cost.	Standard of Efficiency.	——	Actual Value. Present Condition.	New.	Good.	Indifferent.	Bad.
£.	£.			£.	£.	£.	£.
8·23	4·11	Painting . .	Good . .	..	5·38	..	..
4·51	2·26	Buffers . . .	Bad . . .	..	..	..	0·21
162·24	81·12	Brass tubes .	Bad . . .	..	..	..	7·46
51·22	25·61	Crank axle . .	Indifferent .	..	..	12·60	..
6·63	3·31	Trailing ditto .	Bad . . .	..	..	..	0·30
6·63	3·31	Leading ditto .	Indifferent .	..	..	1·63	..
46·82	23·41	Trailing tires .	2 Bad . .	..	..	..	2·15
46·82	23·41	Leading ditto .	2 Indifferent	..	..	11·52	..
23·41	11·71	Driving ditto .	1 Good . .	..	15·32	..	..
23·41	11·71	Ditto do. .	1 New . .	22·33	..	..	..
9·97	4·98	Axle-boxes . .	4 Good . .	..	6·50	..	..
4·98	2·49	Ditto do. . .	2 Bad . .	..	..	..	0·23
0·89	0·45	Brass valves .	Bad . . .	..	..	..	0·04
0·36	0·18	Slide blocks .	1 set Bad .	..	..	..	0·02
0·36	0·18	Ditto do. .	1 „ Indiffnt.	..	..	0·09	..
180·51	90·25	Fire-box . .	Bad . . .	..	..	..	8·30
0·26	0·13	India-rubber hose-pipe .	Bad . . .	..	..	..	0·01
237·80	118·90	Boiler . . .	Good . .	..	143·87	..	..
697·82	348·91	Other portions of engine .	Standard .	..	..	..	..
1,512·87	756·43			22·33	171·07	25·84	18·72

TABLE 2*a*.

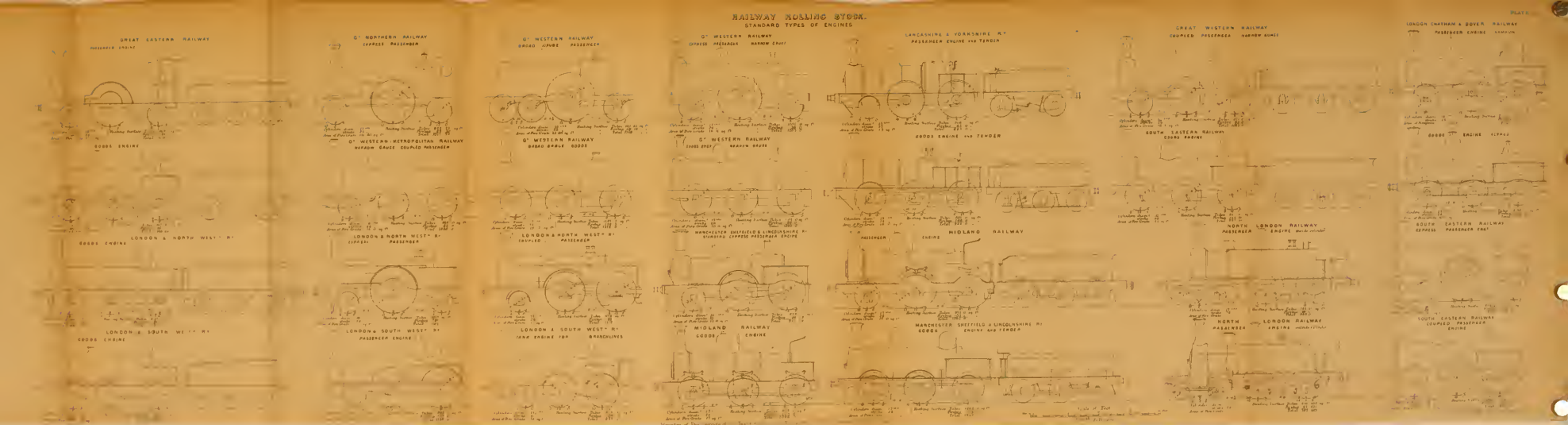
VALUATION of TENDER.

Total Net Cost.	Standard of Efficiency.	——	Actual Value. Present Condition.	New.	Good.	Indifferent.	Bad.
£.	£.			£.	£.	£.	£.
4·57	2·28	Painting . .	Bad . . .	..	..	..	0·19
33·42	16·71	Tender frame .	Indifferent .	..	..	8·09	..
0·42	0·21	Break blocks .	Bad . . .	..	..	..	0·02
9·74	4·87	2 Axles . . .	Good . .	..	6·41	..	..
4·87	2·43	1 Ditto . . .	Bad . . .	..	..	..	0·20
2·08	1·04	2 Axle boxes .	New. . .	2·00	..	..	..
2·08	1·04	2 Ditto do. .	Good . .	..	1·37	..	..
2·08	1·04	2 Ditto do. .	Bad . . .	..	..	..	0·09
0·16	0·08	Buffer blocks .	Indifferent .	..	..	0·04	..
11·79	5·90	Trailing tires .	2 Bad . .	..	..	..	0·50
11·79	5·90	Leading ditto .	2 New . .	11·29	..	..	..
11·79	5·90	Ditto do. .	2 Indifferent	..	..	2·85	..
180·40	90·20	Other portions .	Standard .	..	..	..	..
275·19	137·60			13·29	7·78	10·98	1·00

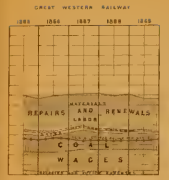
RAILWAY ROLLING STOCK.

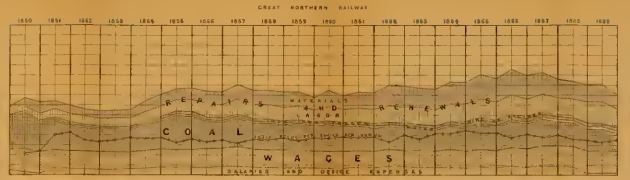
STANDARD TYPES OF ENGINES

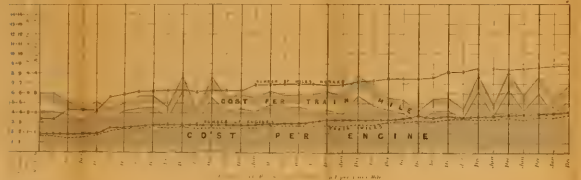
PLATE

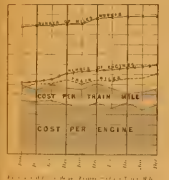


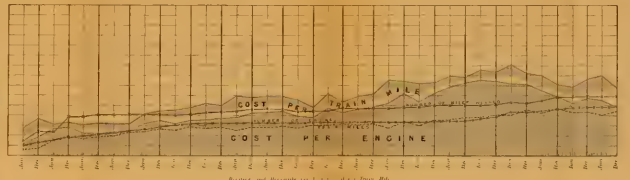
RAILWAY ROLLING STOCK.



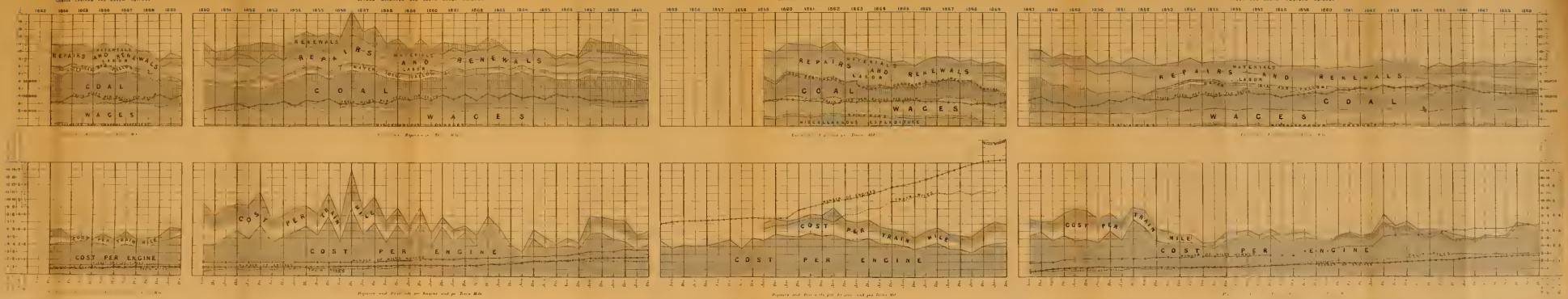




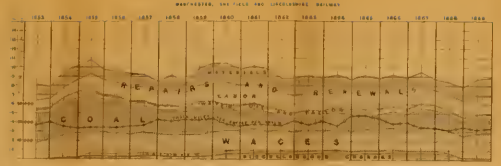


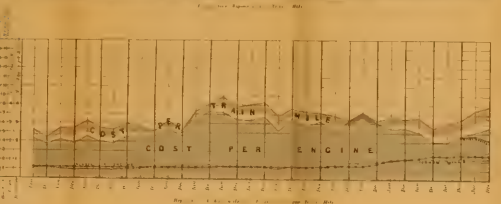


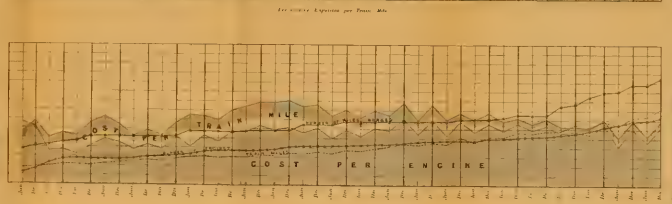
RAILWAY ROLLING STOCK.

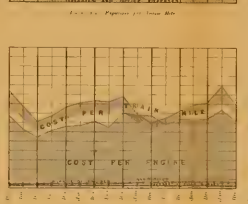


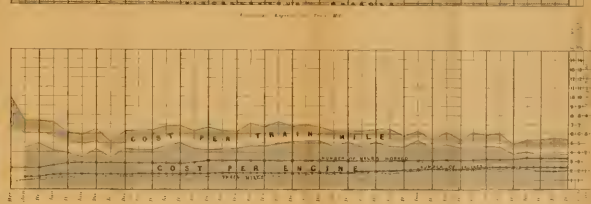
RAILWAY ROLLING STOCK.







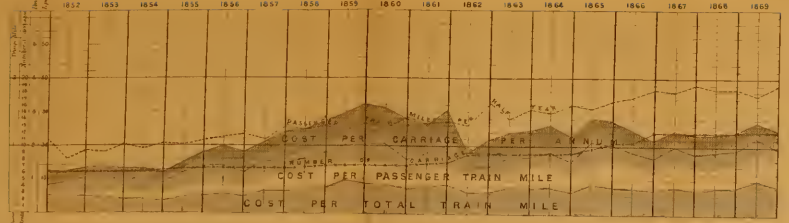




RAILWAY ROLLING STOCK.

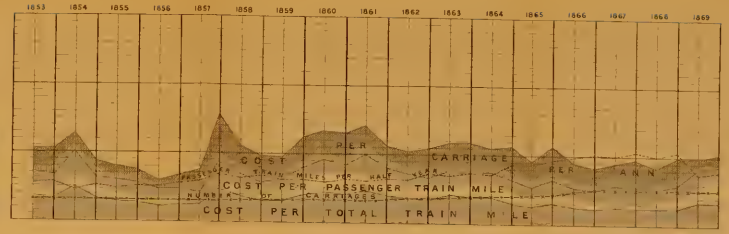
PLATE 17

GREAT NORTHERN RAILWAY



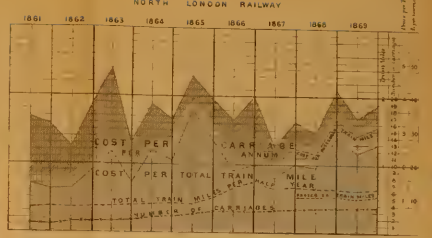
Repairs and Renewals of Carriages

MANCHESTER, SHEFFIELD AND LINCOLNSHIRE RAILWAY



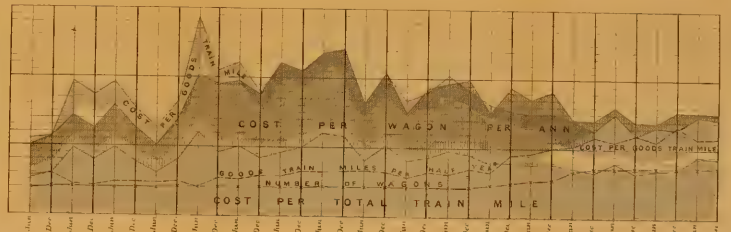
Repairs and Renewals of Carriages

NORTH LONDON RAILWAY

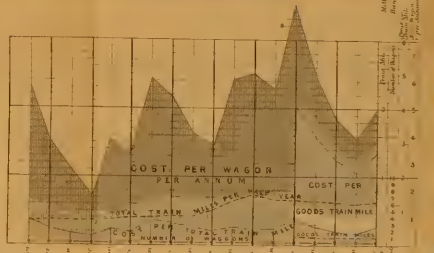


Repairs and Renewals of Carriages

Repairs and Renewals of Wagons



Repairs and Renewals of Wagons



Repairs and Renewals of Wagons

TABLE 3*a*.

SUMMARY of RESULTS of VALUATION in TABLE 1*a* and 2*a*.

Engine:		
Standard of Efficiency		£756·43
Actual condition:		
New portions	£22·33	
Good ditto	171·07	
Indifferent ditto	25·84	
Bad ditto	18·72	
Standard ditto	348·91	
Total actual value	£586·87	586·87
Total amount below standard		£169·56
Tender:		
Standard of efficiency		£137·59
Actual condition:		
New portions	£13·29	
Good ditto	7·78	
Indifferent ditto	10·98	
Bad ditto	1·00	
Standard ditto	90·20	
Total actual value	£123·25	123·25
Total amount below standard		£14·34

Mr. R. Price Williams said he was afraid, in his endeavours to condense a very wide subject within reasonable limits, that some points had not been made as clear as he could have desired, more particularly in respect to the diagrams. Figs. 6 to 17 (Plates 14, 15, and 16) showed, for periods varying from five to twenty-four years, the cost per train mile of the different locomotive charges, the number of train miles, the miles worked, the number of engines per mile worked for each half-year, and the number of train miles per engine per annum, on twelve of the principal railways in England. It would be observed that the scale applicable to the miles worked over was identical with that of the number of engines, enabling the ratio of the one to the other to be estimated very nearly at a glance. This ratio would be found to vary from 0·45 of an engine per mile on the London and South Western and the Great Eastern railways, to 1·05 on the Lancashire and Yorkshire, and 1·95 on the North London railways. The outlines showing the average number of train miles per engine per annum, and their excess or deficiency from the standard of 20,000 miles per engine formed an important element. The diagrams likewise showed the cost per train mile of the repairs and renewals of the engines, the materials in each case being distinguished from the labour. On some of the railways, such as the London and Brighton and the Great Western, the cost of the repairs and of the renewals were kept separate, although, in his opinion, there was no occasion for any such distinction, repairs and renewals being in reality one and the same thing. The other outlines showed the cost per train mile of the water, oil and tallow, coals and wages, which constituted the locomotive running expenses.

It would not fail to be noticed that, as a rule, whenever the train mileage in any half-year showed an increase, the cost of each and all of the various items in the locomotive charges, on the contrary, showed a perceptible decrease; an indication which went a long way to show the insufficiency of the train mileage principle in itself, as a true measure or test of the locomotive expenses on any railway, and its still greater incorrectness when considered as a standard of comparison between the expenses on different railways. Figs. 6 to 17 (Plates 14, 15, and 16) also showed the cost of the renewals per train mile and per engine. Here, again, it would be observed that in many instances the respective outlines in no way corresponded, and that there was often no relation whatever between the cost per engine and the cost per train mile.

On Figs. 18 to 23 (Plate 17) the cost of carriage and wagon repairs and of renewal expenses were shown per vehicle and per train mile; and were worked out both per passenger train mile and per goods train mile. There, too, the respective outlines in no way conformed. Mr. Adams, the Locomotive Engineer of the North London railway,

could probably explain the exact nature of the peculiarities, and the causes which operated to produce the apparently higher cost, of the locomotive and rolling stock expenses on that railway.

He had received from Mr. Armstrong, the Locomotive Engineer of the Great Western railway, a letter which bore upon the subject of the Paper, and from which the following was an abstract :—

"I have found, in dealing with the question of comparison of railway expenses, that there is some danger in attempting to compare things which, in themselves, are to a great extent dissimilar; and in looking over your table, it has occurred to me to mention, that in order to make a statement of this kind of real practical value, the various lines should be classified according to their respective circumstances. Thus, for instance, it would be of little use to compare a line like the London and South Western with the North Eastern, on account of the great disparity which exists in the proportions of passenger and goods traffic. It will also be found, in the case of the London and South Western railway, that the proportion of passenger mileage to goods is as 23 to 8, or nearly three times as much passenger as goods traffic, while on the North Eastern railway the proportion of passenger and goods is as 29 to 48, the goods and minerals in this case being 62 per cent. of the whole mileage.

"This is upon the last half-year's working, but it will be found, I think, very much the same in previous half-years."

There was one other observation he had to make, and that was with regard to the Great Eastern railway train mileage. Mr. Johnson, the Locomotive Engineer of that line, had drawn his attention to the question of what ought properly to constitute train mileage. Mr. Johnson was of opinion that, in addition to other things, the ratio of the shunting and marshalling mileage to the whole train mileage ought to be taken into account; and he had kindly furnished a statement (Table 9), giving in detail all this infor-

Table 9.—Great Eastern Railway.

Proportion of Shunting, Piloting, &c., to Train Mileage. Half Year ending December 31, 1869.

——	Train Miles.	Shunting, &c.	Per Centage.
		Train miles.	Per cent.
Train miles, passenger .	2,134,477		
Ditto, goods	1,716,145		
Total train miles. .	3,850,622	.. ..	100,000
Goods shunting . . .	.. ..	458,382	.. .. 11·901
Piloting	.. ..	66,978	.. .. 1·740
Light running . . .	.. ..	59,923	.. .. 1·556
Ballasting.	.. ..	36,388	.. .. 0·945
Coaching	.. ..	31,309	.. .. 0·813
Assisting	.. ..	17,611	.. .. 0·457
	.. ..	670,591	.. .. 17·415

mation in the case of the Great Eastern railway, from which it appeared that the actual percentage was very considerable.

He had only to add, that permanent way valuations had been prepared just in the same way as the locomotive valuations had been dealt with. It was, in fact, having had to prepare permanent way valuations of this kind, that in the first instance directed his attention to the application of the same principle to rolling stock valuations; but, inasmuch as the permanent way had a less number of parts, he had been able to condense these tables into a more limited form, as would be seen by reference to Table 10,[1] which contained every possible combination from a perfectly new road to a very bad road.

Mr. Vignoles, President, said it was impossible to over-estimate the pains and labour which Mr. Williams had taken; and he could say most truly, that if there had been an enthusiast like him twenty years or thirty years ago, who would have followed out the details and statistics of railways as Mr. Williams had done, many serious errors might have been avoided. It was more particularly due to Mr. Williams to state, that he had done as a private individual what the efforts of continental governments in reference to their railways had not been able to accomplish. The records of Russia, Austria, and Prussia showed what they had attempted to do, but they had never yet succeeded in giving so complete an analysis as had now been accomplished.

Mr. J. T. Harrison remarked that the Paper was upon the question of the deterioration of railway rolling stock generally; but attention had been drawn specially to the locomotive engine, and the arguments had been chiefly founded upon locomotive expenditure; and to that he would confine his remarks. There were four distinct charges upon the revenue of a railway company due to the locomotive department, viz., interest on the capital invested, running expenses, cost of ordinary repairs, and cost of renewals.

The interest on capital had an important bearing on the number of engines required for a certain amount of work. If the number was excessive, the interest might become a heavy charge on the revenue; for instance, a London and North Western engine running 16,000 miles per annum on the average, would take thirty-seven and a half years to execute the 600,000 miles considered in the Paper as due from it during its lifetime; and the simple interest, at 5 per cent. during that period, would amount to £4,125, or 1·65 penny per train mile; whereas a South Western engine running 21,000 miles per annum would do the work of its lifetime in twenty-eight and a half years, and the interest would amount to £3,135, or nearly £1,000 less during its life than the North

[1] This Table may be consulted in manuscript at the Institution.

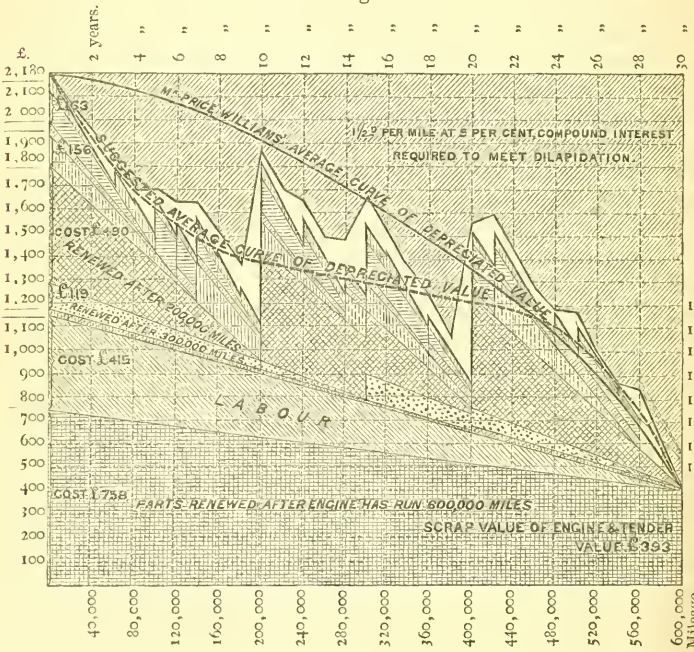
Western engine, and the cost per mile run would be 1·25 penny, or ·4 penny per mile less. The limit should apparently be determined by the number of engines daily in steam, or the number required to replace any that were disabled, and the conveniences the company had for speedily executing the ordinary repairs and periodical renewals.

The running expenses and ordinary repairs must be provided for from day to day, and these necessarily became direct charges on the revenue account. The extent of ordinary repairs would no doubt be greatly influenced by the condition of the engine, "good, indifferent, or bad," as pointed out in the Paper; but the actual value of the engine at any period of its life was not so dependent on its condition. For instance, the condition of an engine might be actually bad after it had run 200,000 miles, when accumulated renewals, involving an outlay of £500, were required, and when this sum was expended upon it, it might fairly be classed again as good. The question was different with respect to renewals. Renewals did not so distinctly meet a railway company from year to year, and demand an expenditure out of revenue. An engine might be in use for nine years with an expenditure of only £57·5 per engine per annum. Then suddenly there might come a demand for an outlay of £500 or £600. For the next twelve years there might be an expenditure of £185·5 per annum, and for the following nine years an expenditure for renewals of only £52 per annum; and the engine, after the 600,000 miles were run, might require that complete renewal which was tantamount to building a new engine.

The way in which he thought it would be well to examine this question was, to consider it as if an engine were supplied by a contractor for the use of the railway company. What would a contractor furnishing an engine demand? Suppose he had expended £2,200 upon the engine. He would first require a return of 5 per cent. upon his capital, and he might fairly say to the company, "You must pay me at per mile run, according to the traffic that you put the engine to. If it is to run only 16,000 miles a year—so much: if 20,000 miles, so much—according to the peculiar traffic. But you must guarantee me, as a minimum, 5 per cent. upon the capital. If the engine runs more than the stipulated number of miles, I get a little benefit by it." Then again he would stipulate that the company should pay the running expenses of the engine and the ordinary repairs, so as to keep the engine while running on the railway in good working order. But besides those three payments he must provide that, from the time the engine started upon that railway, there should be an allowance per train mile to meet the cost of renewal; because the contractor should see after his capital. He had invested £2,200 in that locomotive, and he not only wanted his engine to

be in good order, and to get his 5 per cent., but he wanted to know throughout the whole period of the engine's life, that he had got the £2,200 somewhere, either in the value of the engine or at his banker's. Therefore there should be provided a fund which should recoup him for the depreciation of the engine, and enable him to meet the renewals from time to time. Taking the data given by Mr. Williams, that the life of an engine was about thirty years, and that during that time it ran 20,000 miles per annum, or a total of 600,000 miles, Fig. 3 would represent the first cost and the renewals from time to time; above which he had shown that 1½*d.* per train mile run from the commencement, accumulated at the rate of 5 per cent. compound interest, was sufficient to meet the renewals from time to time, as it amounted to about £1,800 after the engine had run 600,000 miles. This sum, together with £393, the scrap value of the engine when broken up, would enable the contractor to replace his old engine by a new one.

Fig. 3.



Railway companies should act in this matter as a locomotive contractor would do. They should be able to show how the capital expended upon the stock of the railway subject to depreciation was represented; whether that stock were locomotive engines, carriages, trucks, or permanent way, or stations and timber bridges. They

should be able to show that the capital expended in the first instance was in their hands somewhere; either in the value of the stock itself, or in the bank, to replace that stock at its first cost, or in new stock paid for out of revenue. If the revenue was charged systematically to meet this depreciation, well and good: if not, what would be the consequence? These payments were due periodically: how were they to be met? If no provision was made for dilapidation, either those payments had to be met by a heavy charge upon the revenue of the current year, or they had to be paid out of capital; or the stock was allowed to become permanently deteriorated; and what was then really the effect? Dividend was paid indirectly out of capital.

He did not think that "the curve of average dilapidation" exhibited by the Author was correct. Mr. Williams made that curve convex, in preference to the straight line which had been previously accepted. He thought instead of the curve being convex it should rather be concave, as he had drawn it on Fig. 3. It would be seen that for nine years there was rapid deterioration, without any large expenditure for renewals. During that period he thought the value of the engine could not keep up to Mr. Williams' line, but considered that it was more accurately represented by the curve in the opposite direction. When large outlays were incurred for renewals, the line of actual value was at once considerably elevated; and if the large annual expenditure incurred during the mid-life of the engine were continued, the life of an engine might extend to forty or sixty years, with some of the important parts of the original machine remaining, to attest the strength of the materials, the excellence of first construction, and the care with which the engine had been attended to. But if the expenditure were reduced to £52 per annum, as for the last nine years, the value of the stock would depreciate at an exceedingly rapid rate.

Mr. D. K. Clark was of opinion, that the chief object of the Paper was to show, that the depreciation of rolling stock increased in the ratio of the square of the time the engine worked, or more properly as the square of the miles run by it. Now, depreciation, by ordinary tear and wear, signified the reduction of the serviceable or wearing value of an engine or vehicle, or of any part of it, such value being measured by the life of the piece; that was to say, by the number of miles it was capable of running from the time it commenced to work until it was worn out. Depreciation was, therefore, in simple proportion to the mileage run, subject to partial restorations of the value of the engine by the renewal of parts. The principle of valuing each piece of an engine in terms of its life and cost, as a means of arriving at the value of the whole engine, was a sound one, and when properly applied must lead to exact results. It was by no means new, however. He had proposed and

adopted it three years ago, for the valuation of the rolling stock of a large system of railways, and found it easy, expeditious, and satisfactory. But in his opinion the mode in which it was proposed to be applied by the Author must lead to erroneous conclusions.

Taking the cost of a locomotive as supplied by the Author in Table A *a*, the following table showed the life in miles run, the net cost of the pieces and the percentage of the net cost in parts of the given original cost of the engine:—

—	Life in Train Miles.	Net Cost.	Net Cost in per Cent. of the Gross Cost.
		£.	
Indiarubber pipe	10,000	·26	·014
Painting	80,000	8·23	·45
Brass tubes, &c.	100,000	162·24	8·81
Crank axles, &c.	120,000	51·22	2·78
Tires, &c.	140,000	156·88	8·53
Boiler, &c.	200,000	482·38	26·21
Motion, Cylinders, &c. . . .	300,000	107·96	5·87
Lubricator, &c.	340,000	3·18	·17
Clack-boxes, &c.	400,000	17·45	·95
Axles, wheels, &c.	600,000	523·07	28·42
Total net cost of engine . . £		1,512·86	82·20
Scrap value of engine		327·64	17·80
Gross cost of engine . . . £		1,840·50	100·00

The scrap value of the whole engine was in round numbers 18 per cent. of the gross cost, and the sum of the net costs of the pieces was 82 per cent., making together 100 per cent.—the gross cost. From these data, he had taken out the successive depreciations and fluctuations of value of the engine as a whole, in the form of percentages of the gross cost, for successive mileages run, at intervals of 40,000 and 50,000 miles, up to 600,000 miles, which the Author assumed to be the life of the engine, and found them as given in the following Table.

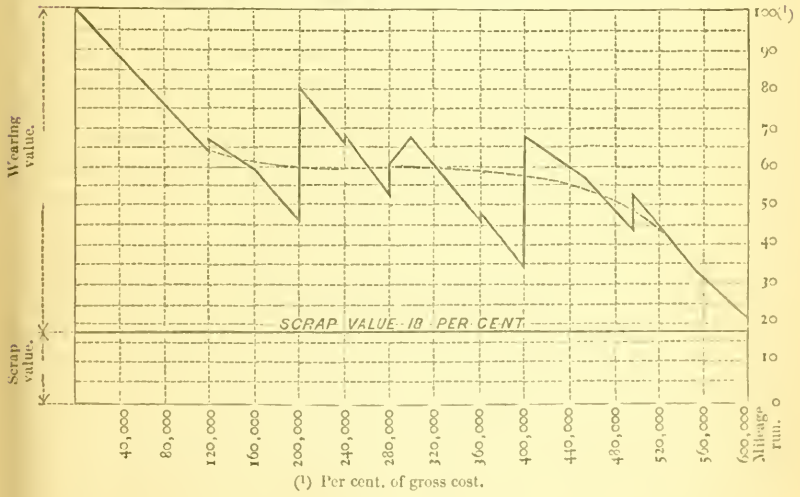
	Net or Wearing Value.
	Per Cent.
At the commencement.	82·2
After 20,000 miles run	76·0
,, 40,000 ,, ...	70·3
,, 80,000 ,, ...	58·6
,, 120,000 ,, ...	45·8 / 48·5
,, 160,000 ,, ...	42·0
,, 200,000 ,, ...	63·7
,, 240,000 ,, ...	47·8 / 50·0

	Net or Wearing Value. Per Cent.
After 280,000 miles run	35·26 / 44·0
,, 320,000 ,,	42·5
,, 360,000 ,,	26·5 / 31·3
,, 400,000 ,,	16·4 / 51·0
,, 450,000 ,,	41·4
,, 500,000 ,,	26·4 / 35·3
,, 550,000 ,,	16·6
,, 600,000 ,,	2·87
Add 17·80 per cent. for scrap value	17·8
Final value	20·67

The values in brackets were the values before and after having had renewals of pieces. The final wearing value, at 600,000 miles, was less than 3 per cent., and the final value, including 17·8 per cent. for scrap, was 20·67 per cent. The diagram, Fig. 4, showed clearly that, contrary to the ordinary doctrine, and to the theory of the Author, the depreciation of an engine as a whole proceeded most rapidly at the beginning of the life; obviously because all parts

Fig. 4.

Current Value of a Locomotive in Percentages of the Gross Cost.



(1) Per cent. of gross cost.

were depreciating simultaneously, and the course of depreciation was not arrested or retarded by any renewal. At the end of 20,000 miles run, the engine had depreciated 6 per cent.: at the end

of 80,000 miles run the depreciation was $23\frac{1}{2}$ per cent., or a fourth of the gross cost of the engine; but at the end of 80,000 miles additional, after the first important renewals had been made, the depreciation was only increased by $16\frac{1}{2}$ per cent.; and so on. A mean curve line, traced to show the average course of depreciation, indicated that the value of the engine in the middle stage of its life was practically uniform,—about 60 per cent. of the gross cost. The depreciation proceeded rapidly towards the end of the life, when, as at the beginning, every part was wearing out together without any relief from renewals. The average total value of the engine, according to this curve, was 58 per cent. of the gross first cost, and the average wearing value was about 40 per cent., or about half of the new wearing value—82 per cent. These figures differed considerably from the results deduced by the Author, whose figures were considerably in excess, as they showed an average or 'standard' total value of 73 per cent. of the gross cost: that was to say, two-thirds of the total net cost plus scrap value.

It was not easy to perceive the utility of the quantity called the 'money life' of an engine, which in one place was described to be the number of years in which were executed a quantity of renewals equal, in first net cost, to the net cost of the engine. In another place (Table 4), the money life was obtained by dividing the gross cost of the engine by the actual net expenditure in material and wages for repair per year. These two modes of finding the money life were obviously incompatible, for whereas, in the first mode, net cost was compared with net cost, in the second net cost for repair was compared with gross cost. Besides, the wages for current repair were generally equal to the cost for material; but in the net cost of a new engine, the wages, as the Author had shown, were little more than a fifth of the net cost for material. It thus appeared, that there was no analogy whatever between the net cost of a new engine, and the current cost for repair of an engine; and that 'money life' was an ideal quantity of no practical utility.

Mr. W. Adams said the North London railway stood out rather prominently with regard to expenses of working; he was, therefore, glad to have the opportunity of explaining some of the causes which were involved in the expenses of working the traffic. The journey over the North London line was a very short one, and therefore the cost of working the goods and mineral traffic bore a large proportion comparatively to the total mileage incurred: that was to say, there was a great deal of shunting mileage at both ends of the journey. Traffic of that kind, compared with the traffic on long lines, where the shunting was comparatively less, placed a line like the North London in a disadvantageous position. The passenger traffic was carried on mostly by trains that stopped and started frequently at numerous stations. A great deal of the

power of the engines was therefore thrown away; for as soon as the engine got into full speed the break was put on. It was stated by the Author, that it would be an excellent plan if some uniform system of dealing with mileage were adopted. In that he quite agreed. He did not know the system pursued on other lines, but he would state what was the practice on the North London. With regard to pilot engines, he did not use them for drawing trains. The trains on the North London were such as one engine was capable of hauling with comparative ease. Occasionally light engines were run over the line, in which case they were always attached to trains, and the mileage was charged as light mileage, and not as train mileage. The renewals in the case of the North London railway had been exceptionally heavy in the six and a half years during which the expenses of that line had been estimated. At the present time six engines and twelve carriages were renewed per annum; and these appeared as a heavy charge in proportion to the repairs. For the half-year ending June, 1868, the expenditure on locomotive repairs amounted to £7,572, and on renewals to £4,500. For the succeeding half-year the cost of repairs was £7,400, and of renewals £4,550; and in 1869 they amounted to about the same sum. Of course, in order to make a fair comparison, these matters should be taken into account.

Mr. W. Martley remarked that it was difficult to compare the accounts of locomotive and carriage repairs, owing to the different manner in which they were made out on various lines of railway. On the London, Chatham, and Dover railway a number of engines were in steam so long daily, that two sets of men were required to work them. This work could not, therefore, be fairly compared with that on the London and North Western railway, or other long lines. Those engines with two sets of men did not give a good mileage per engine, in fact only about 70 miles per day per engine; and the expenses per engine were very heavy with a small mileage to divide them by. He concurred with what Mr. Adams had said as to the lines about London. The traffic on the North London railway was very similar in character to the greater portion of the metropolitan traffic of the London, Chatham, and Dover railway, except goods and coal, which was comparatively small on the latter railway.

On long lines many engines ran a high mileage per day, and this gave a better average per engine. He thought the mileage was seldom calculated in the same way by any two companies. In the case of the London, Chatham, and Dover railway it was made up as on the North London railway. Train mileage was not included for bank or for assistant engines, although these were supplied. In the published mileage accounts, there was great disparity between the train mileage and the engine mileage; and

that was caused, not by the locomotive department, but by the calls of the traffic department to run light engines to meet traffic at points away from where the locomotives were kept. He contended that engines employed on such work should have their mileage computed in both directions, instead of only getting mileage for the actual distance the train ran.

Mr. Bramwell said that, had time allowed, he would have brought before the Meeting some statistics relating to one of the oldest wagon companies in England. He understood the Author of the Paper to say, that the depreciation of a locomotive engine might be looked upon, not merely as of less percentage of its then value in the first years of its life, but as being absolutely less, and as being greatest of all in the last years. If this were so, the result would be, that a person beginning with new plant would have to charge himself with a depreciation of say 1 per cent. per annum, while one who was using old plant would have to charge himself with say 20 per cent. of its value per annum, because the Author affirmed there was not merely relatively but actually greater depreciation in the last than in the first years of a piece of plant.

That seemed to him contrary to all experience of ordinary depreciation of plant. To test this view of the Author, suppose a railway started with new plant, and afterwards took up an old line, and the plant, at a certain price, half worn out. The locomotive superintendent would have, according to Mr. R. P. Williams, to say, "With respect to this plant half worn out, we must not take that at the same rate of depreciation as we take the new; but we must take off ten times the percentage which we do for the new plant." This seemed to him so monstrous that he felt sure there must be some fallacy in the Author's position; and he thought the fallacy arose in this way:—Mr. Williams had taken the life of a locomotive at thirty years. Mr. Bramwell could not tell why he so took it, because he allowed every part to be renewed except the name-plate and the side frames. If wheels, tubes, axles, and fireboxes were renewed, why should renewals not embrace the side frames and the name-plate. It appeared to him there was no reason why they, in common with other parts, should not be renewed, and if they were, then the engine would have no termination to its life; it would, in fact, go on,—a new blade and a new handle, and a new handle and a new blade,—so as to keep in existence perpetually. If such succession of renewals were made, there would be obtained, instead of the curved diagram of the Author, having its edge indented by a number of varying triangles, a succession of uniform triangles, having a straight line for their common base, and the value of such a figure would be half that of the original cost of the stock. It appeared to him that what

a railway company had to do was to arrive at the cost of that which he would call endowed plant. This required that there should be either spent, or partly spent and partly laid aside, in every year, such a sum of money as would complete the repairs properly called for within that year, and would provide an accumulating fund to defray the cost of the graver repairs which would be required in subsequent years, and to defray the cost of renewals. If this were done, railway companies would then have at all times the original cost of the plant represented by the value of that plant as it stood, and by the cash invested for the purposes of heavy repairs and renewals.

Mr. HARRISON, Vice-President, observed that an engine when new might be applied to the running of express trains where it would earn a large amount of money; but after a time it would not be in a condition for running express trains, and it would be put on to run short stopping trains, and ultimately it would be used as a pilot engine. Therefore there was a decrease in its earnings, and an increase in cost of maintenance, and the engine, though in existence, could not be of its original value. The Tables given by Mr. Williams were of the greatest possible importance to the railway interest, and much valuable information might be derived from the contemplation and study of the diagrams. He laid before the Meeting, more for the sake of curiosity than anything else, some extracts from the books of the North Eastern railway, showing the statistics of three engines, for a period of twenty-five years—giving the prime cost, the number of miles run each half-year, the amount of expenditure under the heads of ordinary and extraordinary repairs, and an estimated amount of the depreciation, based upon the results of ten years' previous experience. In twenty-five years these engines had each run an average of 575,000 miles of engine mileage, or 490,000 miles of train mileage, which was equivalent to about 23,000 engine miles, or 19,000 train miles per annum. The expenditure in ordinary repairs was £2,161 and in extraordinary repairs £4,213, making the total cost £6,374, or £255 per engine per annum. On looking over the cost of engines on the North Eastern railway for many years, he found the average was £250 per engine per annum, and it hardly varied £5 above or below that amount. Such results depended, however, upon the circumstances of each individual railway, and he could not exemplify that more strongly than by taking two sections of the North Eastern railway, where the engines were applied differently. In one case, where there was a much larger proportion of mineral traffic than in the other, the cost per engine was £270 per annum, while in the latter instance it was only £255. When such differences existed on different portions of the same railway, it was evidently impossible

to draw general reliable conclusions, and to compare the results of railways like the London, Chatham, and Dover with the London and North Western. The mode of calculating the train mileage was as various as it was possible to be. The large companies had lately adopted the actual train mileage run as the basis, and, all things considered, it was the best; but, at the same time, this principle might tell more in favour of one company than of another, in making a comparison of the cost of working, owing to the difference in the number of pilot engines.

It had been suggested that it was necessary to charge a certain amount annually against the revenue of the company for depreciation. Theoretically that might be right; but he never yet met with a body of railway directors who were willing to adopt such a course, nor did he think it was necessary, and in a report made twenty-five years ago he adopted that view. It was not the mere question of the life of an individual engine that had to be considered, but the average life and average condition of the whole stock of engines. He found the average depreciation of a large number of engines might be considered as 30 per cent. or 33 per cent.; and that was as nearly as possible a constant. No doubt if a larger amount of money had been allowed for the maintenance of stock in the infancy of railways, the shareholders would have reaped the benefit; but he did not believe the evil of not having a reserve fund to meet those expenses extended beyond a few years after the opening of a railway.

Mr. Vignoles, President, remarked that, the law having prescribed a certain return only applicable to the train mileage, it could not be employed for the purposes of comparison for different railways. If the extra mileage was taken into account it would amount, he believed, to 10 per cent. upon the whole running of the engine stock. He contended that that account ought to be kept, and though it might be a long time to look forward to, he thought a record of all that was incurred in respect of the cost of engines would result in both engines and trains being contracted for in future. This was, he believed, now done in many places; just as twenty years ago it was not uncommon for a wagon company to supply wagons at a mileage rate. If a correct record of each railway were kept, contractors would be found to furnish the plant, supposing it were not to the interest of the company to do otherwise; and he thought it would be in most cases to the interest of the companies to contract not only for engines, but for everything else at a certain mileage rate. It would be a saving of capital, though interest would have to be paid to the contractors in some shape. He had no doubt that such a system of contracting for rolling stock would encourage railways of a purely agricultural character. Railway statistics had been too much neglected in this

country, and on the continent they were not carried far enough. In his opinion no railway records were so useful, as those which determined anything relating to the current expenses.

Mr. G. H. Phipps referred to the mode recommended by the Author of analyzing the various parts of an engine which were subject to the greatest amount of wear. Twenty years ago, when connected with the then Eastern Counties railway, he always made use of a similar method, and ascertained the value and number of miles that the fire-box, tubes, tires, and other wearing parts would work; and thus when the half-yearly report had to be made out it was easy to debit each of the above parts against any particular engine, by simply knowing the number of miles run. This he considered a useful and practical way of ascertaining the current depreciation independent of the repairs in the shops. The Author of the Paper, by his access to numerous examples, had no doubt brought the above system to a great degree of perfection, and the result, he thought, would be very useful.

Mr. R. C. Rapier referred to a point, which had often occurred to him, as springing out of a discussion involving the whole question of locomotive practice. The drawling way in which trains entered and left the stations on many of the main lines was notorious. At the same time the effective way in which the trains started on the Metropolitan railway, and had done for ten years on the Lancashire and Yorkshire railway, and for fifteen years on the North London railway, must have been a matter of observation. He apprehended the solution lay mainly in the size of the cylinders. The question was necessarily limited by the kind of diagram of performance, and that would limit the size of the cylinder. To explain what he meant, an engine, on starting from a station, was perhaps exerting its full power. If a diagram was taken then, it would be found that, with a pressure of 120 lbs. in the boiler at the commencement of the stroke, there would be an actual pressure of 100 lbs. in the cylinders, and at the end of the stroke of 85 lbs., or thereabouts. It was not so when the engine was going 40 miles or 50 miles an hour. Perhaps the pressure in the cylinders at the beginning of the stroke would then be as low as 70 lbs., and if it was cut off at one-fourth, there would be too low a final pressure for favourable working. He spoke rather from a passenger's point of view, because time was money. Upon some of the railways, three minutes were taken up in putting on the breaks, and four or five minutes in getting up speed after leaving the station. In good locomotive practice the question was, what should be the minimum ending pressure of the steam? What was the lowest point that could be reached in the diagram, for favourable working at the high speeds?

And then for the starting, he would make the cylinders, consistently with that, as large as possible.

Mr. Gregory, Past-President, remarked that, in addition to the size of the cylinders alluded to by Mr. Rapier, there were two other causes to account for the rapidity with which the trains on the North London railway were started and stopped, viz., the driving wheels were of small diameter, and coupled, and continuous breaks were used.

Mr. J. T. Woodhouse said, he preferred the old-fashioned pace on the Midland railway to the sudden impulses of stopping and starting, which were always attended with unpleasant jerks.

Mr. R. Price Williams, in reply upon the discussion, said, Mr. Armstrong had afforded him the information necessary to complete the tables and diagrams of the locomotive expenses on the Great Western railway similar to those he had already prepared of the other principal railways. He felt it due to Mr. Armstrong to add, that in the series of elaborate and carefully prepared tables of the locomotive expenses on all the principal lines in the kingdom during the last five years, which that gentleman had prepared from the published accounts of the companies, and which had been kindly shown to him, his own tables had been, to a certain extent, anticipated. A careful comparison between them confirmed in all respects the correctness of the results he had arrived at. The comparative statement, Table 11, had been prepared by Mr. Armstrong, after reading the Paper, with the object of showing, as it did in a very striking manner, that the charges for the running repairs and renewals on nearly all these railways had been gradually reduced during the period to which the statement referred. The amount these diminished expenses represented was shown in the last column of the table, and Mr. Armstrong particularly drew attention to the case of the London and North Western railway, and to the large reduction which had latterly been made on that railway in the eleven years' average, viz., from 9·31*d.* to 8·17*d.* per train mile, a difference which in money amounted to £110,000 in one year. In accounting for this large saving, Mr. Armstrong paid the highest and most deserved tribute to the eminent Locomotive Engineer of that railway, Mr. Ramsbottom, M. Inst. C.E., ascribing the results chiefly to the many improvements brought about in the machinery and other appliances for economising the amount of labour, and more especially to the successful efforts in introducing standard types of engines, and the most complete system of interchangeableness in the working parts of the engines. Mr. Armstrong was further of opinion that, by scrupulous attention to the quality of the materials and economy in every possible way, the full standard

of an eleven years' average money life would eventually be arrived at.

TABLE II.

MR. ARMSTRONG'S STATEMENT.

NAME OF RAILWAY.	Cost per Train Mile.		Difference between Mr. Williams's Average and Mr. Armstrong's Statements (per mile).		Amount of Difference per Mile upon One Year's Train Mileage present working.	
	As per Mr. Williams's Statement. Average of Years.	As per Mr. Armstrong (Year ending December, 1869).	Over.	Under.	Over.	Under.
	d.	*d.*	*d.*	*d.*	£.	£.
Great Eastern . . .	8·73	8·70	0·03	..	978	..
Great Northern . .	8·46	8·52	..	0·06	.. ..	2,097
Great Western . . .	7·92	7·56	0·36	..	23,819	..
Lancashire and Yorkshire	7·59	7·22	0·37	..	13,379	..
London, Chatham, and Dover	10·30	9·12	1·18	..	11,167	..
London, Brighton, and South Coast . . .	10·95	9·48	1·47	..	25,795	..
London and North Western	9·31	8·17	1·14	..	110,578	..
London and South Western	8·50	7·84	0·66	..	17,153	..
Manchester, Sheffield, and Lincolnshire .	9·19	6·79	2·40	..	38,649	..
Midland	9·04	7·71	1·33	..	85,379	..
North London . . .	12·06	11·99	0·07	..	366	..
South Eastern . . .	9·12	9·31	..	0·19	.. ..	3,148

Mr. Martley had directed attention to some of the existing anomalies connected with the subject of train mileage, and in those views he fully concurred. That the present unsatisfactory method of estimating train mileage did not, as Mr. Martley showed, admit of any reliable comparison being made between the working expenses on different lines, was admitted by all leading railway men; and that a more satisfactory and reliable basis could be arrived at, by the exercise of a little trouble and discussion, was as generally admitted. He confessed he had not been without hope, that a common and reliable basis might have resulted from a discussion of the tentative method suggested in Tables 4 and 5. However, the question whether it was desirable to adopt a nominal 18,600 train mileage per engine had not been dealt with; but he adopted it, first, because it was, according to Mr. Ramsbottom, the utmost which, with due regard to efficiency, could be got out of an engine; and in the next place, it happened by a coincidence to be almost exactly the average of the train mileage of the whole of the railways he had dealt with. He still thought that such a nominal train mileage did enable a closer and more reliable comparison to be

made between the relative expenses on different railways, due regard being had to the peculiar characteristics of the respective traffics.

He had been struck with the absence of all comment upon the facts elicited from Messrs. Sacré and Webb's engine valuations, and his own deductions therefrom, in regard to what he had termed the mean money life. He did not consider it his province to do more than bring the leading facts under the notice of the Institution, leaving it to individual members to draw their own conclusions; but in this case, having himself had some practical acquaintance with locomotive construction, he was not at all prepared, on first going into this question, for the remarkable results arrived at, viz., that although the ultimate life of an engine might be as much as thirty years, yet practically, and for all useful purposes, the mean life of an engine was no more than eleven years. In other words, as stated in the Paper, such an amount would be spent upon an engine in that period as would completely replace its net cost. As an illustration of what this 'mean money life' of an engine meant, he might state that, in the case of the London and North Western railway, with fifteen hundred engines, it represented £3,717,000, which was equivalent to £338,000 per annum spent in that short time, in the renewals necessary to maintain the stock at its full standard of efficiency. In the case of the London and South Western railway, with its long mileage and very limited number of engines, £692,000 had been spent in the short space of 8·8 years, equivalent to £865,000 in eleven years. Supposing, however, the locomotive stock on that line to have had the ordinary average life of eleven years, instead of 8·8 years, the difference between these two sums, viz., £173,000 would have been saved in the course of the latter period. On the other hand, the extra capital required to purchase the additional engines necessary to bring up the locomotive stock of the London and South Western railway to the standard average, viz., from 0·45 to 0·78 of an engine per mile worked, would have amounted to nearly £548,000, showing, as Mr. J. Thornhill Harrison had pointed out, that in the case of this particular line at least, a small rolling stock worked to its utmost mileage gave the most economical results. It was, he thought, a fair question for consideration whether on lines, such as the London and North Western and the Great Northern, notwithstanding the large amount of mineral traffic, &c., a considerable amount of capital was not uselessly locked up, in the possession of a larger stock of engines than was necessary: whether, in fact, a shorter life, and a larger mileage per engine, obtainable by working double shifts, would not be more economical.

The practical importance of a reliable method of ascertaining the running or serviceable value of a stock of engines, carriages, and

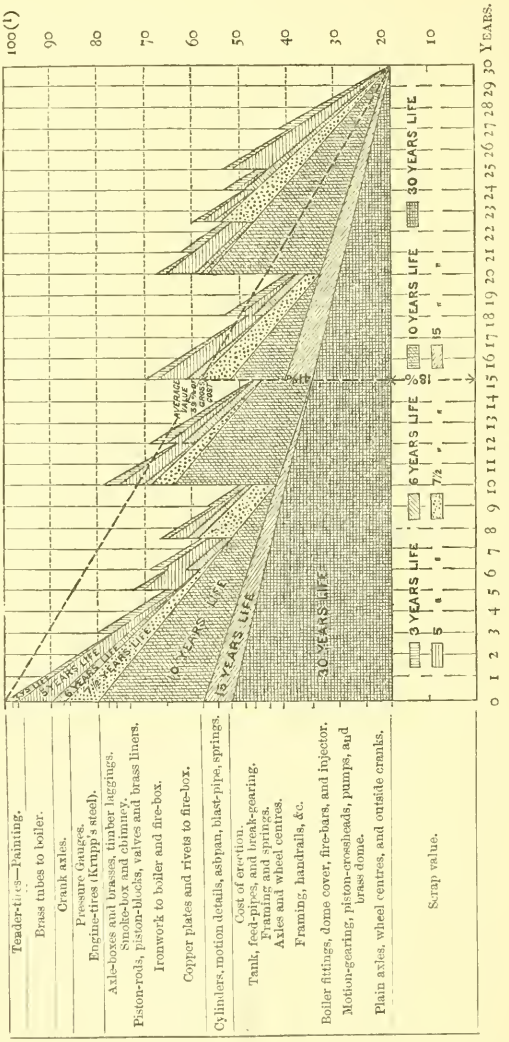
wagons, on a given mileage of railway, together with its permanent way, works, &c., had often been forced upon his attention. The necessity, for instance, of such valuations on a line about to be amalgamated with another, must have repeatedly presented itself. Indeed, it was having had to do with such investigations as these, that first led him to pursue the subject in the way he had done, and to apply the principle of this system of valuation, not merely for the purposes above referred to, but, as stated in the Paper, to enable the exact amount of depreciation of the road and the rolling stock to be ascertained at any time, in order to satisfy the shareholders that neither the one nor the other had been allowed to get below the full standard of efficiency. That both the rolling stock and the road of some railways had, at unfortunate periods of their history, been permitted to lapse into a depreciated condition, in order to pay a large and unearned dividend, no one who had any knowledge of railway history would deny; and this neglect had resulted in the entire absence of dividends on some railways. He agreed that, supposing a stock of engines to be kept up to their full standard of efficiency, the cost of the renewals would become a constant quantity. A striking illustration of this fact was instanced by Mr. T. E. Harrison, in the case of the almost unvarying annual cost of the renewals during a long series of years on the North Eastern railway. That there must be a certain and definite amount of what he had called normal depreciation in a stock of engines, or a permanent way continually exposed to rapid and variable rates of wear, must be equally admitted, whether that was, as he contended, $\frac{1}{3}$rd of the net cost, or some larger coefficient. Admitting, for a moment, that the depreciation increased directly as the time or mileage run, a glance at diagram Fig. 5 would show, that the average line of depreciation for all parts of an engine was that indicated by the dotted straight line. In proof of this he might state that, before adopting the curved outline, he had assumed a uniform rate of depreciation for all the parts, calculating the value of each part separately on that very principle, from the break block up to the longest-lived portions,[1] by taking half the net cost for each item during the whole period of its life.

The result arrived at by the summation of the values of each of the separate items gave exactly half the whole net cost of the engine, as might be expected, inasmuch as the sum of the halves of any number of parts was manifestly equal to half the entire sum of such parts. It followed, therefore, that the straight dotted

[1] The detailed valuation of a locomotive engine and tender, based on the assumption of the straight line of uniform wear, would be found in the Appendix to the Paper, side by side with the valuation, based on the curved or variable line of depreciation.

line gave the average running value of the engine; at the same time, as pointed out both by Mr. Kinnear Clark and Mr. J. Thornhill Harrison, the actual value of a particular engine at any given

Fig. 5.

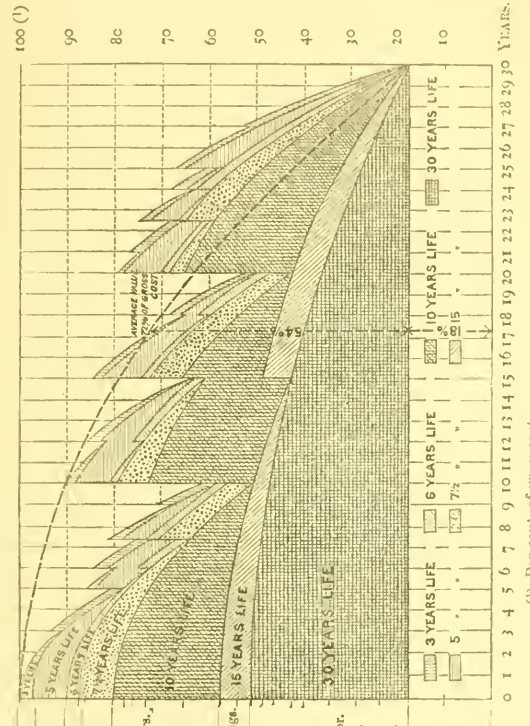


(1) Per cent. of gross cost.

period of its life, where the renewals had occurred exactly in the sequences shown on the diagram, would be measured by the ordinates of the irregular serrated outline shown on his own

diagram, and those of Mr. Harrison and Mr. Clark. But he could not see what was the practical use of the mean curve line shown on those gentlemen's diagrams, inasmuch as the value of the

Fig. 6.



(1) Per cent. of gross cost.

engine at any given time, supposing the renewals to take place in the exact order shown, was measured by the ordinates of the irregular outline itself, and not by any mean curve such as they had

indicated. It must be obvious that his curved outline was never intended to apply to a condition of uniform wear, as assumed by Mr. J. T. Harrison. He had stated that the adoption of the curved outline involved the assumption that the wear was not uniform; and that such was the case with most of the wearing parts of the engine no one had attempted to deny. The diagram Fig. 6 was merely an amplification of the diagram Fig. 2, showing, however, the details from which the serrated curved outlines in the diagram Fig. 2 had been constructed. The diagram Fig. 5 showed similar details on the assumption of uniform wear. It was not intended that the curve of average depreciation should represent the nearest 'give and take' line to the serrated outline shown on the diagram Fig. 2, or such as Mr. D. K. Clark's and Mr. Harrison's diagrams represented. It was, in reality, the average of a great number of smaller parabolic curves, the joint area of which was equal to that of the larger one, as would be seen by reference to the diagram Fig. 6. On the assumption of uniform wear, as shown in the diagram Fig. 5, the curve became the straight line, and the area of the large triangle was equal to the sum of all the areas of the minor triangles, corresponding to each individual part. The average curve in the one case and the straight line in the other, showing that the average value of an engine during its whole life, with all its parts wearing out and being renewed at different periods, might, in fact, be considered as if the whole of the parts of the engine had each thirty years' life, or that each had a common mean life of eleven years, and all wore out together at the end of either of those periods.

As regarded the comparison between the cost of current repairs and the first cost, alluded to by Mr. D. K. Clark, he observed that the ratio of the scrap value to the gross cost of a standard locomotive of the present day, given in Table C, was as £393 to £2,191, or a little less than $\frac{1}{5}$th. In the lighter engines, however, of fifteen and twenty years since, much of the work now executed by machinery was then done by hand labour; consequently the scrap value bore a very much smaller proportion to the entire gross cost, the scrap value of a stock of engines of various ages certainly not averaging more than from £240 to £250, or about $\frac{1}{10}$th of the gross cost assumed in Tables 4 and 5. It might also be observed, that the assumed cost, viz., £2,400, was in itself rather a low estimate, the average gross cost per engine on the Midland railway during the last three years having been £2,513, or £113 in excess of that amount, being equivalent to nearly one-half of the average scrap value. The deduction, therefore, of so small a percentage as $\frac{1}{20}$th, or even as $\frac{1}{10}$th, from an estimated average gross cost was not considered necessary, the only object of the Author being to afford some standard of comparison between the

money life values of the engines on the different railways, and at the same time roughly to verify the more exact results given in Tables A, B, A *a*, B *b*, and C. The fact of there being, as there necessarily must be, a greater relative amount of labour in current repairs than in the construction of an entirely new engine, in no way affected the correctness of the "money life results," as Mr. D. K. Clark seemed to imagine. It was clear that, during the so-called period, a sum would actually be spent, partly in labour and partly in new materials, equal to the entire first cost of the engine and tender.

The standard types of engines in use on eleven of the principal railways, with all the leading dimensions, as furnished by the locomotive engineers of the respective railways, were shown on Plate 13.

Mr. Vignoles, President, observed that every possible credit was due to the Author, for facing the difficulties and going through the tedious investigation he must have done, to have arrived at such striking and graphic results as he had exhibited. There were some points, however, on which he differed from him, particularly in what he had last said, where the line of argument was derived from the experience of one or two engines. He thought the degree of authenticity to be given to the conclusions drawn would be specifically modified, in considering the question of a railway with a thousand or fifteen hundred engines, rather than on the limited area to which he had restricted himself. That, however, was too wide a field to enter upon now. His chief object in rising was to assure Mr. Williams that he fully appreciated his labours; and if he had not completely succeeded in solving the question, he had pointed out the right direction in which inquiries should be made.

Mr. S. W. Johnson stated, through the Author, that the rolling stock of a railway could be efficiently maintained and renewed at the following rates of expenditure, viz.:—

	d.	
Engines	3·25	per train mile.
Carriages	1·375	,,
Wagons	1·375	,,
Total . . .	6·0	,,

These rates would be found to correspond very nearly to an annual outlay on first cost of about 10 per cent. on locomotives,
10 per cent. on carriages, and
5 per cent. on wagons.

It was assumed that, with this outlay, two-thirds to three-fourths of the stock might at any time be found classed, in stock-taking, under the head of 'good order,' and it was further assumed that the number of engines in stock corresponded with the work there was to do, that was, that not more than from 50 per cent. to 55 per cent. of

the total stock of engines were in steam daily. The life of a modern locomotive of good manufacture might be taken as expressed by a duty of 500,000 train miles; and the life of locomotives as made some years ago might be reckoned at 400,000 miles. The running expenditure would range from 4·5*d.* to 6·0*d.* per train mile, and the precise figure would be considerably influenced by the cost of fuel in any particular district. Irrespective of this item (after allowing for difference in cost of fuel), running expenses were a good criterion of the condition of efficiency, or otherwise, of the locomotive stock of a railway. It was impossible to maintain an economical running expenditure if an engine stock was allowed to get into bad order.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously—

> "That, in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 26th of April."

April 26, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

The discussion upon the Paper, No. 1,277, "On the Maintenance and Renewal of Railway Rolling Stock," by Mr. R. Price Williams, was continued throughout the evening.

May 3, 1870.

CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

The following Candidates were balloted for and duly elected:—JOHN HENRY EUSTACE HART, ROBERT JONES, WILLIAM MOORE, ALEXANDER LAWRIE NIMMO, PETER SCOTT, and EDWARD BAYLIES THORNHILL, as Members; FRANK MORRIS AVERN, FRANCIS DAVID MILLETT BROWN, R.E., Captain B.S.C., JOHN THEOBALD BUTLER, THOMAS CARRINGTON, Jun., ROBERT ELLIOTT COOPER, WILLIAM FREDERICK CRAWFORD, B.A., JOHN BREEDON EVERARD, Stud. Inst. C.E., ROBERT JOHN GEORGE, GEORGE RUSHOUT GODSON, JOHN ANTHONY KENDREW, GRENVILLE PULTENEY DE PALEZIEUX FALCONNET, Captain R.E., and WILLIAM ROBERTS, Associates.

No. 1,279.—"On the Strength of Iron and Steel, and on the Design of parts of Structures which consist of those materials." By GEORGE BERKLEY, M. Inst. C.E.

THE published results of numerous experiments for testing the strength of wrought iron vary considerably. Some samples have sustained without rupture a stress of nearly 34 tons per square inch of section, while others have broken with less than 20 tons per square inch of section. The absence of uniformity, though it may have arisen from various causes, can be explained in some degree by the well-ascertained fact, that a bar of iron 1 inch square, which will not bear a strain of more than about 26 tons without rupture, will, when drawn into wire $\frac{1}{32}$nd of an inch in diameter, bear a strain equal to about 40 tons on its original (1 square inch) area. This diversity of result is referable to the variations in the quantities of work which have been involved in the production of the particular form of the iron tested, and this circumstance should always be taken into account, in determining the practical tests to be applied. It is not, however, requisite, in order to attain the immediate objects of this Paper, to do more than determine the strength of wrought iron in the forms in which it is commonly used in bridges, roofs, and similar structures, and in which it can be obtained at current market prices.

The strength is probably best represented by the minimum strain which a piece of wrought iron, having a sectional area of 1 square inch, will bear without rupture, and by the amount of stretch which takes place in a given length before it breaks. It is important to

ascertain how much the iron will stretch, because it is possible that it may be able to sustain a large amount of dead weight, though the absence of ductility may cause it to snap with a comparatively small living load. The simplicity, added to the practical efficacy, of these tests, as to strength and ductility, cause them to be the best which can be applied through the medium of an ordinary inspector.

Experience, extending over twenty years, and comprising many thousands of experiments, has proved that a quality of iron can be obtained at the current prices of the day which will bear the following tests. For plates, an average breaking strain of 20 tons per square inch, and a minimum breaking strain of 19 tons per square inch, and an average stretch of 1 inch in 12 inches lineal. For L and T irons, an average breaking strain of 22 tons per square inch, and a minimum breaking strain of 21 tons per square inch, and an average stretch of $1\frac{1}{4}$ inch in 12 inches lineal. For rivet iron an average breaking strain of 18 tons per circular inch. For bars intended for chains, couplings, &c., an average breaking strain of 22 tons per square inch, and an average stretch of $1\frac{3}{8}$ inch in 12 inches lineal.

Experience has also shown, that for ordinary classes of work, let at competitive prices, tests more severe than the above can only with much difficulty be enforced.

With this information in view, it will be desirable to consider the practical limit of strain to which 1 square inch in section of wrought iron, in tension or compression, may safely be subjected—and the principle on which such a limitation rests. This question will be discussed in relation to tension, in preference to compression, as being the more simple.

It is desirable at the outset to free the question from any erroneous impressions. Thus numerous experiments could be quoted to justify the generally-received impression, that 'permanent set' is not produced in wrought iron in tension until a strain of about 10 tons or 12 tons per square inch of section has been applied. It would, nevertheless, be unwise to place reliance on that impression. Sir W. Fairbairn has recorded the results of careful experiments, wherein a 'scarcely perceptible' permanent set appeared after a strain of only 2 tons or 3 tons per square inch; when 5 tons per square inch had been applied the 'permanent set' amounted to the measured quantity of the $\frac{1}{112}$th part of the stretch; with 7 tons per square inch, this was increased to the $\frac{1}{110}$th part of the stretch, and with 10 tons per square inch to the $\frac{1}{60}$th part of the stretch of the iron. Mr. Edwin Clark also states, in his work on the Britannia and Conway bridges, that a measurable amount of permanent set was produced in wrought iron by the application of a strain equal to 3 tons per square inch

of section. This apparent discrepancy, between the results of ordinary experiments and others minutely manipulated, is not remarkable, when it is remembered that the permanent set, with a strain of 10 tons per square inch, only amounts to about the $\frac{1}{1250}$th part of an inch in a length of 5 feet. It would appear, therefore, that there is no good ground for the assumption, that 'permanent set' commences only on the application of a strain of about 10 tons per square inch of section. Under these circumstances, it is necessary to look for some other characteristics of wrought iron, in order to arrive at the principle on which to base the limitation of the strain that may be imposed on it, when employed in works of utility and art.

Experimental research has shown that, upon the application to wrought iron of strains exceeding about 12 tons per square inch, the measure of stretch per unit of strain, which had previously increased in a certain proportion to the units of strain applied, increases with a greater and progressive rapidity. It may be fairly assumed that this change indicates an altered condition of the 'atoms,' or 'centres of force' of which the material is composed; and it is not too much to say, that the practical result should be a distrust of the material when subjected to more than 12 tons to the square inch. It may also be noted, that the amount of stretch actually produced by the imposition of a strain of about 12 tons per square inch would be sufficient frequently to preclude the use of wrought iron so strained.

The influence of repeated strains on the durability of iron must not be disregarded. Experiment justifies the conclusion, that a material like wrought iron may be incapable of sustaining the repeated applications of a force far smaller than that which produces rupture, or even less than that which gives rise to the condition of the greatly augmented stretch before referred to. The well-known experiment of the "Commissioners appointed to inquire into the application of iron to railway structures," on cast iron seems to prove this as regards that metal. It will be remembered that it was reported by the Commissioners, that when a blow from a heavy ball suspended by a wire 18 feet long, from the roof, so as to touch the centre of the side of a bar, "was powerful enough to bend the bars through one-half of their ultimate deflection (that is to say, the deflection which corresponds to their fracture by dead pressure,) no bar was able to stand 4,000 of such blows in succession;" also, that when the bar was thrown into a violent tremor, then "the depressions produced by the machine were made equal to one-half of the ultimate deflection, the bars were actually broken by less than 900 depressions."[1]

[1] *Vide* "Report of the Commissioners," page x. Folio, London, 1849.

The following fact with respect to the influence of repeated strains on Bessemer metal was lately ascertained: four-feet lengths of rails, weighing 68 lbs. to the yard, of this material, placed on firm bearings 3 feet apart, had been tested on successive days, during a long period, by a weight of 1 ton falling on the centre of them from a height of 30 feet, without any piece of rail being fractured by the single blows to which it was subjected, while a deflection of about 7 inches in the length of 36 inches was always produced. A portion of a similar rail was used in testing the strength of cast-iron sleepers, under a falling weight of $3\frac{3}{4}$ cwt. This piece of rail was keyed into the jaws of the sleeper, and rested on two pieces of oak, each 6 inches long and placed 7 inches apart, and received the blows from the falling weight of $3\frac{3}{4}$ cwt. on the centre of the 7-inch space, through the medium of a wrought-iron clip placed on it, to prevent injury to the upper surface of the rail. The piece of rail (the material of which has since been proved to be capable of bearing a tensile strain of 40 tons per square inch) broke, showing an excellent and sound fracture, after receiving 15,400 blows, of which blows 1,000 had resulted from a fall through each of the following heights, viz., 1 foot, $1\frac{1}{2}$ foot, 2 feet, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, and 6 feet, and

	900 blows	from a	fall	through	$6\frac{1}{2}$ feet.
	800	„	„	„	7 „
	700	„	„	„	$7\frac{1}{2}$ „
	600	„	„	„	8 „
	500	„	„	„	$8\frac{1}{2}$ „
	400	„	„	„	9 „
	300	„	„	„	$9\frac{1}{2}$ „
and	200	„	„	„	10 „

With respect to wrought iron, the experiments of Sir W. Fairbairn would seem to show, that when it is desired to repeat the application of strains from 2 to 3 million times, it would not be prudent that such strains should exceed 7 tons per square inch of section.

It appears from these considerations, that the practical strength of wrought iron, in structures of a permanent character, cannot be estimated at more than 12 tons per square inch, when such strain is repeated beyond a small number of times; and that it should not be calculated as exceeding 7 tons per square inch, when strains of this amount will be applied to it many times daily.

These limits must be further reduced by a number of practical considerations, such as the possibility of the weights affecting the structures being increased beyond those estimated, the effect of oxidation from the material being imperfectly protected, and from errors in design.

In some of the principal suspension road bridges, the strain in

tension resulting from the constantly applied load, with the addition of strain from ordinary use, does not exceed 5 tons to 6 tons per square inch, while that strain to which the material may be subjected on extraordinary occasions amounts to from 8 tons to 9 tons per square inch. In railway bridges, which are frequently subjected each day to the maximum anticipated strain, a limit of 5 tons per square inch of section of wrought iron in tension is in this country generally adopted. It may, then, be considered that wrought iron is loaded to within about 25 per cent. of its working strength when applied to permanent structures. This does not seem a large margin of surplus strength to meet practical contingencies and errors of design.

The importance of design being based on sound principles, and on a sufficient knowledge of the results which may be produced by the adoption of various details of construction, is therefore manifest.

In practice, the apparent strength of those parts of a structure likely to be weakened by inequality in the material as manufactured, or by injuries which that material may sustain during the progress of the construction of the work, should be greater than of other parts of the same structure. The parts to which these observations especially apply are the connections of the several pieces of which the structure is composed, and to some of the details to which attention will now be directed.

With respect to ordinary rivetted connections of plates or bars, it is only necessary to say that, although experiment has proved that the power of resistance of wrought iron to a shearing strain is nearly equal to that of the same material to a direct tensile strain, yet it is desirable that the area of the section of the rivets to be sheared, as well as of the plates forming these connections, should be somewhat in excess of the sectional area of the plates or bars which they connect; and that, as the process of punching the rivet-holes in the plates, &c., has a tendency to weaken them, in a greater proportion than that in which the area is decreased, it is advantageous to have all rivet-holes drilled in parts exposed to tension. Were drilling usually specified, it could be effected by means of properly designed tools quite as cheaply as by punching. It is also desirable that the strain on the rivets in such a joint should be resisted equally by all of them. A joint has for many years been adopted to connect the links of suspension bridges, and during the last ten or twelve years has been extensively used in the construction of Warren girders, and other descriptions of bridge-work, roofs, &c.

In the year 1860 some Warren girder bridges were designed for the Great Indian Peninsula railway. These girders, being found convenient for inland carriage, and being easily erected without

much skilled labour (which in India is scarce), have since been adopted to such an extent that, up to the present time, from twenty to thirty thousand links have been required. At an early period, it became a matter of importance to determine the size of the pin and the proportions of the parts of the head, in relation to the size of the bar of the link, which would give a maximum degree of strength at a minimum cost. After about twelve links had been broken, types of which are shown in diagrams Nos. 1, 2, and 3 (Plate 18), the proportions shown by diagram No. 4, were adopted, as presenting a form of head and a diameter of pin of equal strength with the bar. Seven links of the dimensions of No. 1 were broken. Three of these broke, as shown on diagram No. 1, in the neck between the head and the bar. Two broke through the end of the head; one across the centre of the head at the side of the pin-hole, and one on one side of the pin-hole and through the end of the head. The average strain which destroyed these links was equal to 18·38 tons per square inch. The results of these experiments are stated in the Appendix, Table No. 1.

Two experiments were tried with the form of link shown by diagram No. 3, in which the end of the head was made deeper, and the curves of the neck connecting the head and the bar of rather larger radius, while the sides were slightly reduced. These both broke at the sides of the pin-hole, with an average strain, per square inch of bar, of 16·72 tons. Other proportions were then tried, of which one is shown in diagram No. 2, until it appeared to be proved that those of diagram No. 4 gave the desired results. A statement of these experiments is given in the Appendix, Table No. 2.

The proportions adopted were:

The bar	A being 100
The diameter of the pin . .	B = 75
The depth of the head beyond the pin	C = 100
The two sides of the pin-hole .	DD = 125
And the radius of the curve of the neck	R = 150

The description of the fracture and the strain per square inch of bar area sustained in fifty-one experiments, in which links of these proportions and of various sizes were broken or severely tested, are recorded in the Appendix, Table No. 3. The average strain per square inch of bar, at which these links broke, was equal to 23·29 tons. Twenty-three of these links broke in the bar. Twenty-three of them broke across the centre of the head at the sides of the pin-hole; one through the end of the head; one through one side of the pin-hole and the end of the head, and three links were not broken, two of which bore a strain of 24 tons per square inch of

bar area. These results, carefully obtained at various times, in the course of the execution of contracts during the years 1862 to 1869, seem to confirm the correctness of the conclusion, that the desired proportions of links had been arrived at by the consideration of the experiments in the Appendix, Tables Nos. 1 and 2.

On one occasion, in the early part of 1862, it became necessary to reduce the heads of some of the links to the form shown on diagrams Nos. 5 and 5A. This was at first done by shearing the piece off. When, however, some of these were tested, it was found that the head was weakened in a greater degree than had been anticipated. Six of these links were broken, which sustained an average strain of only 15·36 tons per square inch of bar—the maximum strain sustained being 16 tons, and the minimum 14·81 tons per square inch of bar. When this was ascertained, it was determined to plane off the same part of the head, and on breaking three of the links so treated, it was proved that the average breaking strain had been increased to 19·66 tons, the maximum being 20·43 tons, and the minimum 18·25 tons. A statement of the results of nine experiments is given in the Appendix, Table No. 4.

Such questions as the following may be asked: 1st. What will be the effect of increasing the diameter of the pin, at the same time that the proportions of the head remain unaltered, or are to a corresponding extent diminished? And 2ndly, as important works have been constructed with links of different proportions to those described, how is a judgment to be formed respecting the comparative merits of the proportions therein adopted with those stated as affording the most satisfactory results?

In order to give information in reference to the former of these questions, experiments on links of the proportions shown on diagrams 7, 7A, 8, 8A, were tried. In reference to the latter question, the experiments illustrated by diagrams Nos. 9, 9A, to 13 and 13A were arranged. To enable a fair comparison to be instituted between the values of all the proportions of links tested, the requisite number of links were rolled under precisely similar circumstances, formed of iron taken indiscriminately out of the same scrap heap, and tested in one testing machine in exactly the same way.

The series was commenced with two links of what may be called the standard proportions, viz., those shown in diagram No. 4. These broke in the head, as shown in diagrams Nos. 6 and 6A, with strains of 22·5 tons and 21·75 tons per square inch of bar area respectively, or with an average strain of 22·125 tons, which may therefore be assumed as the strength of these links. Diagrams Nos. 7 and 7A show the result as regards strength, of an increase in the diameter of the pin to 4 inches, in place of 3 inches in the

standard form of link, with corresponding reductions in the metal of the head. These links broke with an average strain of 17·46 tons per square inch of bar area.

Diagrams Nos. 8 and 8A show the results of a similar increase in the diameter of the pin, the head being, in other respects, of the standard proportions. These links broke with an average strain of 23·175 tons per square inch of bar area.

Diagrams Nos. 9 and 9A show a link formed of exactly the same proportions as those of the Menai suspension bridge, and the description of fracture and amount of strain with which they broke. The average strain producing rupture amounted to 20·23 tons per square inch of bar area.

In a similar manner, diagrams Nos. 10 and 10A show the proportions of the links of the Pesth suspension bridge, which broke with an average strain of 17·4 tons per square inch of bar area.

Diagrams Nos. 11 and 11A show those of the links of the Chelsea bridge, which broke with an average strain of 19·75 tons.

Diagrams 12 and 12A show the links of the Hungerford bridge, which broke with an average strain of 18·925 tons, and diagrams 13 and 13A show those of the Hammersmith suspension bridge, which broke with an average strain of 20·6 tons per square inch of bar area.

A tabulated statement (No. 5) is appended, showing the proportion of the heads of each of these forms of link in comparison with the width of the bar, the breaking weight per square inch of bar area, the elongation with a strain of 14 tons per square inch, and remarks on other points which it may be desirable to refer to briefly.

The first point to be noticed is the degree of strength which results from the adoption of each of these forms of link. Taking the strength of the standard form (22·125 tons per square inch of bar area) as = 100, the percentage of gain or loss, in power of resistance to ultimate strain, by the use of the other forms of links will stand as follows :—

6 and	6A	= 100·0				
7 „	7A	= 79·9 ;	loss	= 20·1	per cent.	
8 „	8A	= 104·7 ;	gain	= 4·7	„	
9 „	9A	= 92·0 ;	loss	= 8·	„	
10 „	10A	= 79·8 ;	„	= 20·2	„	
11 „	11A	= 89·2 ;	„	= 10·8	„	
12 „	12A	= 85·4 ;	„	= 14·6	„	
13 „	13A	= 93·1 ;	„	= 6·9	„	

Although in the fifty-one experiments with the standard form of link, about an equal number broke in the bars and in the heads, the fracture of all the links, specially tested and illustrated by the diagrams, took place only in the heads. In relation to this, it is interesting to notice the statement of Mr. Provis, in his

work on the Menai bridge, that out of 10,176 links, which were proved with a strain equal to about 11 tons per square inch of bar area, one hundred cracked and forty-seven broke, and that "the fracture was very generally at one of the eyes."[1] From which the practical lesson may be gathered, that the head is the part which is most liable to defects, and that it is desirable, if not actually necessary, to test all links with a strain equal to at least 10 tons per square inch of bar area.

A further examination of the diagrams will afford a clear insight into the causes of fracture in most of the experiments. There can be no doubt that diagrams Nos. 1, 12A, 13, and 13A prove how unmechanical it is to design a junction of a smaller with a larger mass of metal without the intervention of a curve of comparatively large radius in the part connecting them. The loss from this error in design, in the case of the links of the Hungerford bridge, amounts to nearly 15 per cent.

The fact that, in a large number of instances, the links broke across the centre of the head at both sides of the pin-hole, notwithstanding the excess of metal in those parts, amounting to 25 per cent., also proves the truth of this proposition. It is, however, unnecessary to pursue this subject further, as its complete analysis will be found in the Paper on "The influence of form, &c." read at the Meeting of the British Association in 1869, by Mr. Bramwell.[2]

Diagrams Nos. 6, 7A, 8, 9A, 11, and 11A, appear to indicate, that in designing connections the direction of the strain should be truly along the axis of the link or bar, and that the strength of the material on both sides of the head should be equal.

The small diameter of the pins in the links represented by diagrams 10 and 10A and 11 and 11A caused the pins to be much bent when these links were broken, the surface of the pins to be indented, and the back of the head to be thickened, with a comparatively small strain on the area of the bar. It is necessary to bore out such small pin-holes after links of these proportions have been tested, even with strains in the former case of 9 tons and in the latter of 13¼ tons per square inch of bar area, as adopted by the designer of the bars.

The question of the strength of wrought iron in compression, and the design of struts and other members of such structures as have been referred to, and which are subjected to this strain, cannot

[1] *Vide* "Account of the Suspension Bridge over the Menai Straits," by W. A. Provis, p. 87. Folio, London, 1828.

[2] *Vide* "Engineering," August 27, 1869.

be wholly disregarded, although the practical information on this important subject is very limited.

There are probably no parts of bridges, and other analogous structures, about the strength of which there is so much doubt as the members subjected to compression. Notwithstanding that this statement will probably be admitted, the amount of information respecting the characteristics of columns of various materials, lengths, and sections, is, and has been for a considerable period allowed to remain, in an unsatisfactory state. It must also be confessed, that the formulæ proposed for facilitating calculations to determine the strain which such columns will bear, produce results which neither agree one with the other, nor with any series of experiments. It seems probable that for the present, error may be best avoided by referring to the results of experiments made upon columns, &c., the conditions of which are analogous to the case under consideration. If these statements be even approximately true, it is indeed time that the laws of the powers of resistance of struts or pillars of various forms should receive early and serious consideration.

In the Appendix, Table No. 6, a number of experiments have been arranged, so as to show the dimensions of the bars, columns, cylinders, T and angle irons, which have been subjected to compression—the proportions of the length to the maximum diameter —and of the diameter to the thickness of sides—and the strain resisted up to fracture on the whole area—and on each square inch of area. To this information the following observations may be added. 1st. The strain under which wrought iron ultimately fails is equal to about $\frac{4}{5}$ths of that which produces rupture when the same material is subjected to tension. 2ndly. Although the strain under which wrought iron commences to yield excessively (12 tons per square inch of section) appears about the same as that at which it becomes untrustworthy in tension, the practical rule, not to subject this material in compression to more than 80 per cent. of that to which it is subjected in tension, is a prudent limitation under the conditions of uncertainty which now apply to the strength of struts, &c., of various lengths and maximum diameters. 3rdly. Mr. Edwin Clark, after personally conducting the largest series of experiments ever published, states that the strength of a strut, the length of which does not exceed 5 diameters, may be regarded as equal to a cube; that when the length exceeds 5 diameters and is not more than 25, the strut will fail partly from crushing and partly from flexure; and that when the length exceeds 25 diameters it will fail wholly from flexure. It follows, of course, that in the design of struts, pillars, &c., the bearing surface should be as nearly at the largest diameter on all sides as possible, as in the case of a hollow cylinder. 4thly.

Struts with square ends bearing on a corresponding flat surface are twice as strong as when one end is rounded, and three times as strong as when both ends are rounded. These facts suggest for adoption, the practice which is probably now admitted to be the best, viz., that of planing the end of plates or other forms of wrought iron at all joints subjected to compression. They also justify the conclusion, that the connections of such parts, by means of flat-bearing surfaces and rivets, are much stronger than by means of pins—and that struts connected to other members by means of pins should be of a stronger form in the direction across the axis of the pin than in the line of the axis. And 5thly. It is important to apply the compression strain as nearly as possible through the neutral axis of the member compressed.

This subject was carefully analysed and clearly explained by Mr. Phipps at the Institution during the discussion on the Charing Cross Bridge;[1] and Mr. Callcott Reilly exemplified the mode of complying with these conditions in his Paper "On Uniform Stress on Girder Work."[2]

Although the use of cast iron in girders of railway or road bridges, and indeed wherever it would be subjected to tension simultaneously with tremor, or to a violent and sudden disturbance of its molecules, has in a great degree been displaced by malleable iron, yet it remains to this time one of the strongest and cheapest materials which can be employed, where a statical compressive force has to be sustained by struts, stanchions, and columns, the proportions of which do not render them liable to flexure, while it presents special facilities for the adoption of any required form. It therefore continues to be largely used for cylinders, bed-plates, frames and entablatures, pipes, floor and tank plates, cog and spur wheels, and of late years it has been very extensively employed for railway sleepers. In many of these forms, its degree of strength, both in relation to tension and compression, is important. During the last seven years, many thousand tons of cast-iron sleepers have been exported to India, and other foreign parts where timber is scarce, or the climate is unfavourable to the durability of timber. In order to secure a quality of cast iron which would reduce to a minimum the breakages resulting from frequent and careless transhipment, as well as from actual use in the road, the following tests were applied in the case of the cast-iron sleepers provided for the Great Indian Peninsula railway:—"The mixture of metal is to be such as will produce the strongest and toughest castings, and is to be

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 535.
[2] *Ibid.*, vol. xxiv., p. 391.

approved as such by the consulting Engineer. The contractor must cast twice each day, from the same metal as that used in the sleepers, two duplicate bars 3′ 6″ × 2″ × 1″, and two duplicate castings of the form shown on the contract drawing, and exactly 1″ square for a length of $1\frac{1}{2}$″ in the middle. One of the two bars must be tested on edge, on bearings 3 feet apart, by placing weights on the centre thereof, to ascertain its elasticity and breaking weight; and one of the two castings must be tested in a suitable machine of approved construction to ascertain the tensile strength of the iron. The Company's Inspector will reject all sleepers cast on any day when each of the bars will not bear 30 cwt. placed on the centre without breaking, or when each bar does not deflect at least ·29 of an inch before fracture, and when each casting will not bear a tensional strain of $11\frac{1}{2}$ tons per square inch of section. Three sleepers will also be tested each day by a weight of $3\frac{3}{4}$ cwt. falling through 5′ 6″, the same having previously been subjected to blows from the same weight falling through 2′ 0″, 2′ 6″, 3′ 0″, 3′ 6″, 4′ 0″, 4′ 6″, and 5′ 0″ successively after the sand foundation (which shall not be more than 24 inches thick under the centre of the sleeper and laid on a cast-iron bed-plate 8 inches thick, and weighing 2 tons) has been well consolidated to the satisfaction of the consulting Engineer or his Inspector; and whenever every sleeper so tested does not bear these blows without cracking, or showing other signs of failure, the day's make will be rejected. Immediately after every sleeper is cast, it must be protected in a manner which will satisfy the Company's Engineer that the process of cooling will proceed so slowly, that its strength will not in any degree be diminished by too rapid or unequal cooling."

The following are the results of proving test-bars by lateral pressure, and by direct tensile strain, and of testing the strength of the sleepers by a falling weight of $3\frac{3}{4}$ cwt., during the last three years:—

No. tested.	Average Weight borne by 2 inch × 1 inch Bars on 3 feet bearings.	Average direct Tensile Strength borne by Bars 1 inch square.	Average Fall of $3\frac{3}{4}$ Cwt. at which Sleepers broke, after receiving Blows from the same Weight falling 2 feet and upwards by additions of succeeding 6 inches.
	Cwt.	Tons.	Feet.
1,151	33·4	..	..
1,062	..	13·07	..
1,707	..	..	7·75

During the last eight months, the deflection of the 2-inch by 1-inch bars has received special attention. This has averaged during this period ·295 of an inch, with 30 cwt. placed on the centre of the 3 feet bearings; and the height at which the sleepers have on the average broken has risen from rather less than 7·75 feet to 8·26 feet. The proportion between the direct tensile strain, which 1 square inch of cast iron has borne, and that which a test-bar 2 inches by 1 inch placed on 3 feet bearings has supported on its centre, has been 7·75 to 1; but this result would probably not be obtained, if suitable 'gates' and 'flows' were not adopted to secure a quality of iron, tested under direct tensile strain, equal to that which is found at the lower part of the casting of the corresponding test-bars. It has been attempted to place the sleepers in the testing machine under the most unfavourable conditions, to which it can be assumed they will be exposed in ordinary use, at the same time that uniformity of stress is secured on the whole series of tests, without which it is evident that the process would not be reliable.

A few years ago it was considered that strong iron was obtained if the test-bars, 2 inches by 1 inch, placed on bearings 36 inches apart, would support a weight on the centre of 25 cwt.; and at the present time a material which will barely support this test weight is frequently offered as strong iron. It is sometimes said that results obtained from test-bars are not trustworthy; and, it must be admitted, that even when test-bars are honestly produced and proved, the castings run from the same metal may not possess the same degree of strength. In order to determine this point, the experiments detailed in the Appendix, Table No. 7, were tried, with a view to ascertain the comparative strength of precisely similar girders cast with iron of varying degrees of strength, as represented by the ordinary test-bars, and when subjected to a direct tensile strain. The girders were cast of the exact form and dimensions of three of those described in Sir W. Fairbairn's work, entitled "On the Application of Cast and Wrought Iron to Building Purposes."[1]

The results, which have been very carefully arrived at, are as follows:—

The strength per square inch of section is represented—

In Girder No. 1 by

Sir W. Fairbairn's Experiments . .	as =	3,214 lbs.
The first series of special Experiments	as =	4,977 ,,
The second series of ,, ,,	as =	4,977 ,,

[1] *Vide* "On the Application, &c.," p. 17, 8vo., Lond. 1854.

In Girder No. 2 by

Sir W. Fairbairn's Experiments. . .	as =	3,346 lbs.
The first series of special Experiments	as =	5,264 ,,
The second series of ,, ,,	as =	5,308 ,,

In Girder No. 3 by

Sir W. Fairbairn's Experiments. . .	as =	4,075 lbs.
The first series of special Experiments	as =	4,988 ,,
The second series of ,, ,,	as =	6,300 ,,

The strength of the test-bars and the tensile strength of the iron used by Sir W. Fairbairn are not stated; but it may be assumed to be equal to about 25 cwt. placed on the centre of the 2-inch by 1-inch bar, between bearings 3 feet apart, and to the tensile strength of about 7 or 8 tons per square inch; while the strength of the iron employed in the special experiments is represented by a weight, supported by the test-bars, varying from 30 cwt. to 38 cwt., and by a tensile strength varying from 10·25 tons to 13·94 tons.

The results of these experiments seem to prove that the test-bars may be regarded as small girders, from which the strength of larger girders, if cast and employed under similar conditions, may with some degree of accuracy be determined. The conditions referred to are:—1st. The metal run out of the furnace or cupola having been thoroughly mixed. 2nd. The castings and the test-bars, having been so moulded and tested, that the metal at the upper part of both may be subject to the same description of strain; and that such 'gates,' 'risers,' or 'flows,' shall have been employed as will secure the quality of the metal in corresponding parts of both being similar.

This will be more clearly understood when the following particulars are considered:—1st. The strong iron referred to is obtained by the mixture in the furnace of four or five brands, some being harder than others. In order to amalgamate, as far as possible, these different qualities of iron, the furnace should be charged with them mixed in proper proportions in every basketful of metal which is emptied into it. 2nd. There will be a difference of about 16 per cent. between the weight that a 2-inch by 1-inch test-bar will support when cast on edge and proved as cast, and that which it will support when proved with the underside as cast placed at the top as proved; and a difference of about 8 per cent. between the weight the same test-bar will support if cast on its side or end, and proved on edge. This difference it will be necessary to take into consideration in estimating the strength of a large casting made from the same metal as that used in the test-bars.

Another, and probably the most important practical considera-

tion, in respect of the strength of castings, is the proportions of their several parts being such as will free them as much as possible from unequal contraction in cooling. It is not often practicable to effect that which would avoid this, viz., to adopt an equal thickness of metal in all parts of the casting; and it is therefore important that some means should be taken to prevent the castings from cooling too quickly.

Since the process for the production of steel, invented by Mr. Bessemer, has been largely adopted, and as a consequence this material has been produced extensively, and at comparatively low prices, much interest has been felt with respect to its characteristics. Its value when used in rails, tires, and axles, seems to be established by practical experience; but as a substitute for iron in plates and bars it does not as yet appear to have inspired confidence, although beyond doubt considerable advantages would follow, if it could be safely employed in boiler work, or in ties and struts of bridges, or in roofs of large spans, especially where the cost of such classes of work is enhanced by the charges for conveyance to, and erection in, distant parts of the world. The consideration of its strength and other characteristics must, therefore, be of interest. In the month of March 1866, it was stated at the Institution[1] that the results of thirty-seven experiments showed that this description of steel had a tensile strength, on an average, equal to 42 tons per square inch of section. It also appeared that this material yielded under a pressure of about 18 tons per square inch, and that in tension the yielding point seemed to be arrived at when subjected to this stress, or to a somewhat higher degree of strain.

At that period it was considered desirable, that further experiments of a more complete and satisfactory character should be tried, and a few Civil Engineers formed themselves into a committee for this purpose, to defray the cost of which a fund was liberally subscribed by some of the principal manufacturers of steel. The details of these experiments and summaries of the results will be found in the "preliminary series" published in the year 1868, and in a second series now about to be printed. A copy of both these publications will be presented to The Institution of Civil Engineers. The preliminary series consisted of 203 experiments, to test the resistance of steel to tension, compression, transverse strain, and torsion, and were tried at the testing works of Mr. Kirkaldy. The second series comprised 84 experiments on its power of resistance to tension and compression. During the same period, of nearly four years, numerous experiments have likewise been tried in the course of ordinary practice. In Appendix, Table No. 8,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 387.

some results of practical tests of the tensile strength of Bessemer steel of which rails have been made are given. An examination of these results will, it is believed, justify the adoption of the following conclusions. 1st. That Bessemer steel will bear before rupture a minimum tensile strain of 33 tons per square inch of section, and stretch about 1 inch in 12 inches of its length. 2nd. That the same material will bear either in tension or in compression a minimum stress of 17 tons, before the extensions or reductions of length per unit of strain become irregular or excessive, as compared with those which have preceded them: in other words, before the yielding point of the material is reached. 3rd. That this material will probably contain about ·45 per cent. of carbon chemically combined with the iron. And 4th. That this description of steel, if properly made and annealed, is as uniform in quality as wrought iron, and may therefore be employed (precautions being taken to test its quality) as a substitute for wrought iron, while allowing an increase of strain of 50 per cent. to be imposed upon it.

It is hoped that members of The Institution of Civil Engineers will add largely to the statements contained in, or appended to, this Paper, in order that those which have been submitted for consideration may be corrected or more completely substantiated.

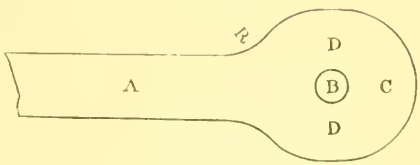
The communication is accompanied by a series of diagrams, and by a reduced drawing, from which Plate 18 has been engraved.

APPENDIX.

Table No. 1.

Proportions of Bar and Head.

A = 100
B = 60
C = 85·7
D D = 114
R = 85·7

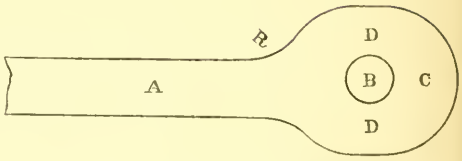


Date of Experiment.	Breaking Weight, Tons per Square Inch of Bar.	Description of Fractures.
9 October, 1860	20	Across neck, 4 inches from pin-hole; fracture 9½ inches long; breaking weight thereon 15·2 tons per square inch.
22 November, ,,	19·5	Through end of head.
3 January, 1861	16·55	Across neck; fracture 8 inches long; breaking weight thereon 13·82 tons per square inch of area.
,, ,,	20	Through one side, and end of head.
16 March, ,,	21·3	Across centre of head, sides of pin-hole.
24 June, ,,	16·02	Across neck.
,, ,,	16·04	Through end of head.
	18·38	Average of seven experiments.

Table No. 2.

Proportions of Bar and Head.

A = 100
B = 65
C = 93 & 100 & 120
D D = 124 & 135
R = 93

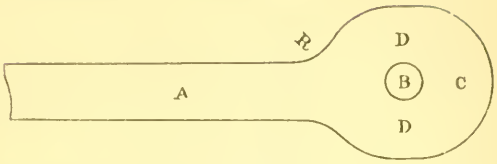


Date of Experiment.	Breaking Weight, Tons per Square Inch of Bar.	Altered Proportions.				Description of Fractures.
		B	C	D D	R	
20 June, 1861	21·7	65	100	120	93	Across centre of head, sides of pin-hole.
21 ,, ,,	21·8	65	100	120	..	Across bar.
21 ,, ,,	22·44	65	100	120	..	Across centre of head, sides of pin-hole.
29 ,, ,,	20·25	65	93	124	..	Through end of head; sides partially ruptured.
10 July, ,,	21·66	65	120	135	..	Across bar.
2 September, ,,	21·23	75	100	125	..	Across bar
6 ,, ,,	21·80		..	..		Across bar } Hammered bars.
6 ,, ,,	23·61		..	..		Across bar
29 October, ,,	23·52	..	100	125	..	Across centre of head, sides of pin-hole.
19 February, 1862	21·15	..	100	125	..	Across bar.

TABLE No. 3.

PROPORTIONS OF BAR AND HEAD.

A = 100
B = 75
C = 100
D D = 125
R = 150



Date of Experiment.	Breaking Weight, Tons per Square Inch of Bar.	Description of Fractures.
23 July, 1862	23·90	Through bar.
24 ,, ,,	20·95	Through bar; iron appeared to have been burnt.
25 March, 1863	22·66	Across centre of head, sides of pin-hole.
25 ,, ,,	23·	Across centre of head, sides of pin-hole.
30 ,, ,,	23·73	Across bar.
30 ,, ,,	23·92	Across bar.
29 April, ,,	22·25	Across centre of head, sides of pin-hole.
29 May, ,,	22·65	Across centre of head, sides of pin-hole.
29 ,, ,,	24·05	Not broken.
15 July, ,,	23·33	Across bar.
2 November, 1867	24·73	Through one side and end of head.
,, ,,	23·00	Across centre of head, sides of pin-hole.
,, ,,	23·22	Across centre of head, sides of pin-hole.
23 ,, ,,	23·75	Across bar.
,, ,,	24·8	Across bar.
,, ,,	23·45	Across bar.
30 ,, ,,	23·41	Across centre of head, sides of pin-hole.
,, ,,	22·98	Across centre of head, sides of pin-hole.
,, ,,	23·82	Across bar.
14 December, ,,	23·92	Across bar.
,, ,,	23·12	Across bar.
,, ,,	22·95	Across bar.
,, ,,	23 85	Across centre of head, sides of pin-hole.
21 ,, ,,	23·1	Across centre of head, sides of pin-hole.
,, ,,	23·8	Across centre of head, sides of pin-hole.
,, ,,	22·98	Across bar.
,, ,,	23·3	Across bar.
4 January, 1868	23·20	Across bar.
,, ,,	23·24	Across bar.
18 ,, ,,	24·5	Across centre of head, sides of pin-hole.
25 ,, ,,	23·75	Across centre of head, sides of pin-hole.
11 July, 1868	22·00	Not broken.
,, ,,	21·00	Across bar (flaw in bar).
18 ,, ,,	23·00	Across centre of head, sides of pin-hole.
,, ,,	20·5	Across side and end of head; flaw in end.
,, ,,	23·00	Across centre of head, sides of pin-hole.
1 August, ,,	25·00	Across centre of head, sides of pin-hole.
,, ,,	22·00	Across centre of head, sides of pin-hole.
,, ,,	23·00	Across centre of head, sides of pin-hole.
,, ,,	23·00	Across centre of head, sides of pin-hole.

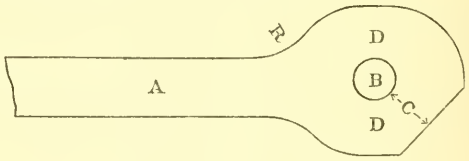
PROPORTIONS OF BAR AND HEAD—*continued.*

Date of Experiment.	Breaking Weight, Tons per Square Inch of Bar.	Description of Fractures.
15 August, 1868	24·00	Not broken.
,, ,,	25·00	Across bar.
5 September ,,	21·00	Across centre of head, sides of pin-hole.
,, ,,	24·00	Across centre of head, sides of pin-hole.
12 ,, ,,	22·00	Through centre of head, sides of pin-hole.
11 July ,,	23·25	Across bar.
12 ,, ,,	22·75	Through end.
1 December, 1869	24·00	Through bar
,, ,,	26·05	Through bar — Made under the hammer, without any cross weld.
,, ,,	26·00	Through bar
,, ,,	24·05	Through bar

TABLE No. 4.

PROPORTIONS OF BAR AND HEAD.

A = 100
B = 65
C = 66
D D = 120
R = 93



Date of Experiment.	Breaking Weight, Tons per Square Inch of Bar.	Description of Fractures.
15 September, 1862	14·81	Broke across end of head at C
,, ,,	15·79	Broke across end of head at C — The piece of head at C had been sheared off these bars.
,, ,,	14·87	Broke across end of head at C
27 ,, ,,	15·57	Broke across end of head at C
,, ,,	16·00	Broke across end of head at C
,, ,,	15·11	Broke across end of head at C
	15·36	Average.
27 September, 1862	20·43	Broke across end of head at C — The piece of head at C had been planed off.
,, ,,	20·31	Broke across end of head at C
,, ,,	18·25	Broke across end of head at C
	19·66	Average.

NOTE.—The above bars were made under the hammer without any cross weld.

TABLE No. 5.

No. of Illustration.	Proportions. A	B	C	D D	R	Breaking Weight, Tons per square inch of Bar.	Mean Breaking Weight, Tons per square inch of Bar.	Elongation with 14 tons per square inch of Bar. In 5 feet of Bar.	In 7 ft. 7 in. including head.	Number of Experiments.	Observations.
								Inch.	Inch.		
1	100	60	85·7	114	85·7	..	18·38	..	..	Seven.	
2	100	65	93	124	93	..	20·25	..	..	One.	
3	100	68	93	104	100	..	16·725	..	..	Two.	Tested by Mr. Kirkaldy.
4	100	75	100	125	150	..	23·29	..	..	Fifty-two.	
5	100	65	Special.	124	93	..	15·38	..	..	Six.	Part of head *sheared* off.
5A	100	..	..	..	..	..	19·66	..	..	Three.	Same part *planed* off.
6	100	75	100	125	150	22·5	22·125	·06	..	Two.	Head began to scale at 11 Tons per sq. inch.
6A	100	..	..	..	..	21·75		·08	·09		,, ,, 12 ,, ,,
7	100	75	87·5	100	150	16·72	17·46	·095	·19		Holes elongate 1 ·01 in. at 10 Tons per sq. in.
7A	100	..	..	..	..	18·2		·08	·24	,,	Head began to scale at 12 Tons.
8	100	100	100	125	150	23·6	23·175	·07	·095		Pin-holes elongated ·005 in. at 13 Tons per sq. in.
8A	100	..	..	..	..	22·75		·07	·13	,,	
9	100	94	73	146	..	19·3	20·35	·065	·13		Pin-holes elongated ·005 in. at 10 Tons.
9A	100	..	..	..	..	21·4		·08	·12	,,	Scaling began at 14 Tons.
10	100	43	66·6	100	..	17·0	17·4	·13	·21		Pin-hole elongated ·005 in. at 8 Tons.
10A	100	..	..	..	..	17·8		·06	·08	,,	Pin indented after 8 Tons, and much bent.
11	100	53·1	81·25	112·5	..	19·4	19·75	·07	·085		Pin-hole elongated at 8 Tons. Pin much indented.
11A	100	..	..	..	..	20·1		·06	·08	,,	Pin indented at 10 Tons. Head at back of Pin thickened ·06 in.
12	100	67·8	78·6	132	..	18·55	18·925	·07	·09		Pin-hole elongated ·005 in. at 12 Tons.
12A	100	..	..	..	..	19·3		06	·08	,,	Head at back of Pin slightly thickened at 14 Tons.
13	100	57	97	105·5	180	20·5	20·6	..	..		
13A	100	..	..	..	..	20·7		..	..	,,	

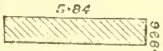
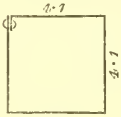
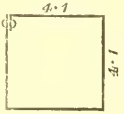
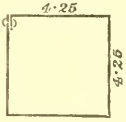
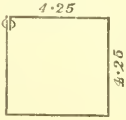
TABLE No. 6.—

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inch.	Sq. Ins.	Inches.	
E. Clark . .		W. I.	90·0	1·024	1·049	..	88·0
Ditto . . .		,,	60·0	1·024	1·0486	..	58·6
Ditto . . .		,,	30·0	1·023	1·0475	..	29·3
Ditto . . .		,,	15·0	1·023	1·0465	..	14·6
Ditto . . .		,,	7·5	1·023	1·0465	..	7·3
Ditto . . .		,,	3·75	1·023	1·0465	..	3·65
Fairbairn and Clark . .		,,	120·0	·503	1·498	..	238·56
Ditto . . .		,,	120·0	·766	2·306	..	156·6
Ditto . . .		,,	120·0	·995	2·975	..	120·0
Ditto . . .		,,	120·0	1·51	4·53	..	80·0
E. Clark . .		,,	90·0	·5023	1·498	..	179·0
Ditto . . .		,,	90·0	·9955	2·9915	..	90·0
Ditto . . .		,,	90·0	1·53	4·59	..	59·0
Ditto . . .		,,	90·0	·995	5·8307	..	90·0
Ditto . . .		,,	60·0	·507	1·511	..	118·0
Fairbairn and Clark . .		,,	60·0	·507	1·498	..	119·28
E. Clark . .		,,	60·0	·767	2·309	..	78·0

BARS.

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
..	10,236 Tons 4·57	9,753 Tons 4·354	2	
..	18,106 ,, 8·083	17,268 ,, 7·709	2	
..	26,530 ,, 11·843	25,327 ,, 11·307	2	
..	36,162 ,, 16·144	34,554 ,, 15·426	2	
..	50,946 ,, 22·744	48,682 ,, 21·733	2	
..	.. ..	.. ..	..	Bore 23·549 Tons without fracture.
..	1,222 ,, ·545	8,157 ,, ·363	..	
..	7,793 ,, 3·479	3,379 ,, 1·5	..	
..	12,735 ,, 5·685	4,280 ,, 1·91	..	
..	46,050 ,, 20·556	10,165 ,, 4·537	..	
..	3,614 ,, 1·613	2,410 ,, 1,076	3	
..	29,619 ,, 13·22	9,912 ,, 4·425	2	
..	91,746 ,, 40·958	19,987 ,, 8·923	1	
..	54,114 ,, 24·158	9,280 ,, 4·143	1	
..	8,469 ,, 3·78	5,604 ,, 2·502	3	
..	8,496 ,, 3·792	5,653 ,, 2·523	..	
..	29,955 ,, 13·372	12,969 ,, 5·79	2	

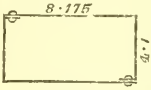
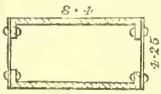
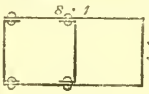
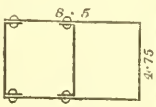
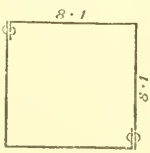
TABLE No. 6.—

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inches.	
E. Clark . .		W. I.	60·0	·995	2·995	..	60·0
Ditto . . .		,,	60·0	·996	5·8166	..	60·0
Ditto . . .		,,	30·0	·5026	1·5011	..	60·0
Ditto . . .		,,	30·0	·763	2·297	..	39·0
Ditto . . .		,,	30·0	·996	2·988	..	30·0
							RECTANGULAR
Fairbairn and Clark . .		,,	120·0	4·1	·504	·03	29·26
E. Clark . .	Ditto	,,	60·0	..	..	..	14·6
Ditto . . .	Ditto	,,	30·0	..	..	..	7·3
Fairbairn and Clark . .		,,	120·0	4·1	1·02	·06	29·26
Ditto . . .		,,	120·0	4·25	1·484	·083	28·23
E. Clark . .	Ditto	,,	60·0	..	1·52	·085	14·1
Ditto . . .	Ditto	,,	30·0	..	..	..	7·0
Fairbairn and Clark . .		,,	120·0	4·25	2·4	·134	28·23

BARS—*continued.*

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
..	54,114 Tons 24·158	18,067 Tons 8·066	2	
..	102,946 ,, 45·958	17,698 ,, 7·901	1	
..	25,299 ,, 11,294	16,853 ,, 7,524	3	
..	63,786 ,, 28·476	27,767 ,, 12·396	2	
..	88,610 ,, 39·558	29,655 ,, 13·239	2	
TUBES.				
136·0	5,534 ,, 2·47	10,980 ,, 4·9	..	
136·6	5,803 ,, 2·59	11,513 ,, 5·14	..	
136·6	6,251 ,, 2·79	12,402 ,, 5·537	..	
68·0	19,646 ,, 8·77	19,260 ,, 8·598	..	
51·0	37,354 ,, 16·675	25,171 ,, 11·237	..	
50·0	35,850 ,, 16·0	23,584 ,, 10·529	..	
50·0	41,674 ,, 18·6	27,417 ,, 12·24	..	
31·7	51,690 ,, 23·076	21,537 ,, 9·614	..	

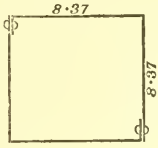
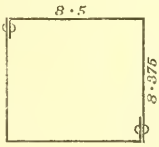
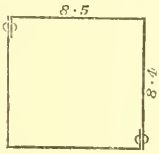
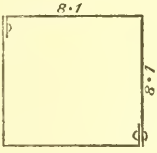
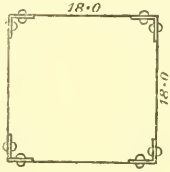
TABLE No. 6.—RECTANGULAR

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Ins.	Sq. Ins.	Inches.	
E. Clark . .	See page 238.	W. I.	90·0	..	..	..	21·1
Fairbairn and Clark . .		,,	120·0	4·1	1·532	·061	29·26
E. Clark . .	Ditto	,,	92·0	..	..	..	22·4
Ditto . . .	Ditto	,,	28·0	..	..	..	6·8
Fairbairn and Clark . .		,,	120·0	4·75	7·326	·264	25·3
Ditto . . .		,,	120·0	4·25	6·9	Channel ·25 Plate ·125	28·23
Ditto . . .		,,	120·0	4·1	1·885	·059	29·26
E. Clark . .	Ditto	,,	91·5	..	..	..	22·3
Ditto . . .	Ditto	,,	44·0	..	..	..	10·7
Ditto . . .	Ditto	,,	19·5	..	..	..	4·7
Fairbairn and Clark . .		,,	120·0	4·75	8·346	·25	25·3
Ditto . . .		,,	120·0	8·1	2·070	·06	14·8
E. Clark . .	Ditto	,,	92·0	..	..	..	11·3

TUBES—*continued.*

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
31·7	55,562 Tons 24·8	23,201 Tons 10·358	..	
67·0	23,289 ,, 10·392	15,221 ,, 6·795	..	
67·2	24,843 ,, 11·09	16,215 ,, 7·239	..	
67·2	24,395 ,, 10·89	15,921 ,, 7·108	..	
18·0	197,163 ,, 88·0	26,900 ,, 12·0	..	
17·0	206,571 ,, 92·22	29,937 ,, 13·364	..	
70·0	43,673 ,, 19·497	23,169 ,, 10·343	..	
69·0	45,451 ,, 20·29	24,111 ,, 10·764	..	
68·3	41,259 ,, 18·415	21,889 ,, 9·772	..	
68·3	49,035 ,, 21·89	26,010 ,, 11·61	..	
19·0	did not fail 207,990 ,, 92·852	not broken 24,909 ,, 11·12	..	
135·0	27,545 ,, 12·296	13,306 ,, 5·94	..	
135·0	27,531 ,, 12·20	13,301 ,, 5·938	..	

TABLE No. 6.—RECTANGULAR

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inches.	
Fairbairn and Clark. .		W. I.	120·0	8·37	4·926	·139	14·33
Ditto . . .		,,	120·0	8·375	7·74	·219	14·33
Ditto . . .		,,	120·0	8·4	8·46	·245 ·238	14·33
Ditto . . .		,,	120·0	8·1	3·55	·063	14·8
Ditto . . .	Ditto	,,	120·0	8·1	..	..	14·8
E. Clark . .	Ditto	,,	60·0	..	..	..	7·4
Ditto . . .	Ditto	,,	28·0	..	..	..	3·4
Fairbairn .		,,	96·0	18·0	50·0	·5	5·33

TUBES—*continued.*

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
60·0	100,395 Tons 44·819	20,364 Tons 9·09	..	
38·2	198,955 ,, 88·819	25,704 ,, 11·475	..	
35·7	not crushed 208,733 ,, 93·184	not crushed 24,673 ,, 11·0	..	
128·5	70,070 ,, 31·281	19,738 ,, 8·811	..	
128·5	82,027 ,, 36·619	23,106 ,, 10·315	..	
128·5	82,411 ,, 36·8	23,208 ,, 10·361		
128·5	85,771 ,, 38·29	24,153 ,, 10·783	..	
36·0	1,523,200 ,, 680·0	30,461 ,, 13·6	..	

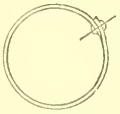
TABLE No. 6.—

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inches.	
							CYLINDRICAL
Fairbairn and Clark . .		W. I.	120·0	1·495	·444	·1	80·0
E. Clark . .	Ditto	,,	60·0	..	..	..	40·0
Ditto . . .	Ditto	,,	30·0	..	..	..	20·0
Fairbairn and Clark . .	Ditto	,,	120·0	1·964	·61	·104	60·0
E. Clark . .	Ditto	,,	60·0	..	..	..	30·5
Ditto . . .	Ditto	,,	30·0	..	..	..	15·3
Fairbairn and Clark . .	Ditto	,,	120·0	2·49	·804	·107	47·8
E. Clark . .		,,	60·0	2·49	·804	·107	24·1
Ditto . . .	Ditto	,,	30·0	..	..	..	21·0
Fairbairn and Clark . .	Ditto	,,	120·0	2·35	1·605	·242	51·0
E. Clark . .	Ditto	,,	30·0	2·383	1·651	·246	12·5
Ditto . . .	Ditto	,,	30·0	2·343	1·407	·21	12·8
Ditto . . .	Ditto	,,	29·0	2·373	1·554	·231	12·2
Fairbairn and Clark . .	Ditto	,,	120·0	2·34	1·435	·216	51·28
E. Clark . .	Ditto	,,	60·0	2·35	1·472	·22	25·5
Ditto . . .	Ditto	,,	60·0	2·335	1·371	·205	25·7
Ditto . . .	Ditto	,,	30·0	2·335	1·435	·205	12·8
Ditto . . .	Ditto	,,	30·0	..	1·435	·205	12·8
Ditto . . .	Ditto	,,	29·0	2·313	1·358	·202	12·3

CYLINDRICAL TUBES.

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
TUBES.				
15·0	6,514 Tons 2·9	14,673 Tons 6·55	..	
15·0	13,860 ,, 6·187	31,180 ,, 13·92	..	
15·0	15,204 ,, 6·787	34,220 ,, 15·277	..	
18·8	14,156 ,, 6·319	23,206 ,, 10·359	..	
18·8	20,332 ,, 9·076	33,299 ,, 14·866	..	
18·8	22,572 ,, 10·076	36,980 ,, 16·509	..	
23·27	23,958 ,, 10·695	29,798 ,, 13·30	..	
23·27	28,244 ,, 12·6	35,100 ,, 15·67	..	
23·27	29,364 ,, 13·1	36,489 ,, 16·29	..	
9·7	34,516 ,, 15·40	21,572 ,, 9·63	..	
9·7	54,666 ,, 24·404	33,107 ,, 14·78	..	
11·1	53,770 ,, 24·0	38,214 ,, 17·06	..	
10·27	57,351 ,, 25·6	36,906 ,, 16·476	..	
10·8	31,828 ,, 14·20	22,179 ,, 9·90	..	
10·6	43,180 ,, 19·276	29,330 ,, 13·094	..	
11·4	41,164 ,, 18·376	29,998 ,, 13·392	..	
11·4	52,588 ,, 23·476	36,639 ,, 16·357	..	
11·4	50,796 ,, 22·676	35,389 ,, 15·799	..	
11·6	53,770 ,, 24·0	39,569 ,, 17·665	..	

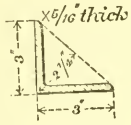
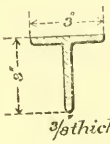
TABLE No. 6.—CYLINDRICAL

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inches.	
Fairbairn and Clark . .	See page 244.	W. I.	120·0	3·0	1·35	·15	40·0
E. Clark . .	Ditto	,,	90·0	3·035	1·414	·168	29·6
Ditto . . .	Ditto	,,	28·0	3·00	1·414	·153	9·3
Fairbairn and Clark . .	Ditto	,,	120·0	4·05	1·707	·14	29·6
E. Clark . .	Ditto	,,	90·0	4·052	1·613	·131	22·2
Fairbairn and Clark . .		,,	120·0	4·06	1·9	·155	29·6
Ditto . . .		,,	120·0	6·36	2·54	·13	18·9
E. Clark . .	Ditto	,,	90·0	6·366	2·547	·13	14·1
Fairbairn and Clark . .	Ditto	,,	120·0	6·18	1·8	·094	19·4
E. Clark . .	Ditto	,,	60·0	6·175	1·799	·101	9·7
Ditto . . .	Ditto	,,	30·0	6·125	1·799	·098	4·9
Ditto . . .		,,	89·0	4·00	2·879	·243	22·2
Ditto . . .	Ditto	,,	89·0	4·00	2·897	·25	22·2
Ditto . . .	Ditto	,,	89·0	4·00	2·873	·242	22·2
Ditto . . .	Ditto	,,	60·0	3·995	2·895	·245	15·0
Ditto . . .	Ditto	,,	60·0	3·995	2·848	·241	15·0
Ditto . . .	Ditto	,,	28·0	4·0	2·845	·25	7·0
Ditto . . .	Ditto	,,	28·0	4·026	2·85	·25	6·95

TUBES—*continued.*

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Number of Experiments.	Observations.
	lbs.	lbs.		
20·0	37,356	27,671	..	
	Tons 16·676	Tons 12·353		
18·0	42,122	29,789	..	
	,, 18·8	,, 13·299		
19·6	52,874	37,392	..	
	,, 23·6	,, 16·693		
29·0	47,212	27,657	..	
	,, 21·076	,, 12·346		
30·9	53,770	33,331	..	
	,, 24·0	,, 14·88		
26·1	49,900	26,263	..	
	,, 22·276	11·724		
49·0	91,402	35,985	..	
	,, 40·80	,, 16·064		
48·9	106,122	41,664	..	
	,, 47·375	,, 18·60		
65·0	60,075	33,375	..	
	,, 26·819	,, 14·899		
61·1	69,002	38,355	..	
	,, 30·8	,, 17·123		
62·5	74,411	41,361	..	
	,, 33·214	,, 18·465		
16·5	74,988	26,046	..	
	,, 33·476	,, 11·628		
16·0	76,780	26,503	..	
	,, 34·276	,, 11·832		
16·5	79,916	27,816	..	
	,, 35·676	,, 12·418		
16·3	86,922	30,024	..	
	,, 36·8	,, 13·404		
16·5	98,122	34,453	..	
	,, 43·8	,, 15·381		
16·0	136,202	47,841	..	
	,, 60·8	,, 21·36		
16·0	138,142	18,576	..	
	,, 61·8	,, 21·68		

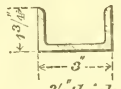
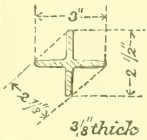
TABLE No. 6.—ANGLE

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inches.	
							ANGLE
David Davis, Kennard Bros., Crumlin .		W. I.	18·0	2·25	1·78	·3125	8·0
Ditto . . .	Ditto.	,,	36·0	2·25	1·78	·3125	16·0
Ditto . . .	Ditto.	,,	48·0	2·25	1·78	·3125	21·3
Ditto . . .	Ditto.	,,	60·0	2·25	1·78	·3125	26·7
Ditto . . .	Ditto.	,,	60·0	2·25	1·78	·3125	26·7
							TEE
Ditto . . .		,,	60·0	3·0	2·1	·375	20·0
Ditto . . .	Ditto.	,,	60·0	3·0	2·1	·375	20·0

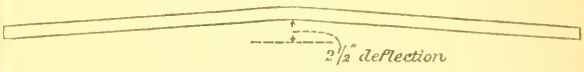
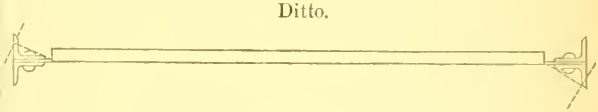
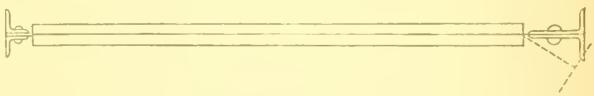
AND T IRONS.

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Observations.
	lbs.	lbs.	
IRON.			
7·2	70,134 Tons 31·30	39,401 Tons 17·589	1 foot 6 inches.
7·2	62,989 ,, 28·12	35,381 ,, 15·795	3 feet.
7·2	52,483 ,, 23·429	29,484 ,, 13·162	4 feet.
7·2	42,000 ,, 18·75	23,595 ,, 10·533	5 feet.
7·2	27·440 ,, 12·25	15,415 ,, 6·88	Ditto.
IRON.			
8·0	62,989 ,, 28·12	29,994 ,, 13·39	Ditto.
8·0	42,000 ,, 18·75	20,000 ,, 8·92	Ditto.

TABLE No. 6.—CHANNEL

By whom the Experiment was made.	Form of Section.	Material	Length.	Least Diameter.	Sectional Area.	Thickness of Metal.	Proportion of Diameter to Length.
			Inches.	Inches.	Sq. Ins.	Inch.	
							CHANNEL
David Davis, Kennard Bros, Crumlin		W. I.	60·0	1·75	2·15	·375	34·2
Ditto . . .	Ditto.	,,	60·0	1·75	2·15	·375	34·2
							CRUCIFORM
Ditto . . .		,,	60·0	2·125	1·88	·375	28·2
Ditto . . .	Ditto.	,,	60·0	2·125	1·88	·375	28·2

AND CRUCIFORM IRONS.

Proportion of Diameter to Thickness of Sides.	Breaking Weight.	Breaking Weight per Square Inch of Area.	Observations.
	lbs.	lbs.	
IRON.			
4·6	38,304 Tons 17·1	17,815 Tons 7·953	Ditto. 
4·6	31,360 ,, 14·0	14,586 ,, 6·5	Ditto. 
IRON.			
5·66	38,304 ,, 17·1	20,379 ,, 9·097	Ditto.
5·66	34,944 ,, 15·6	18,587 ,, 8·3	Ditto. 

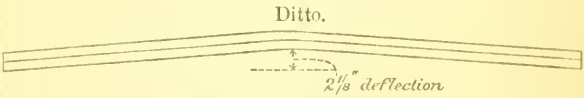
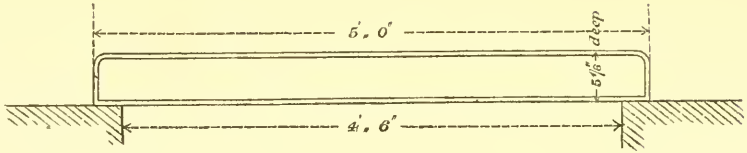
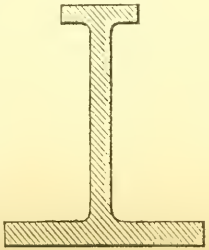



TABLE No. 7.—EXPERIMENTS ON CAST-IRON GIRDERS.

Elevation of Girders Nos. 1, 2, and 3.



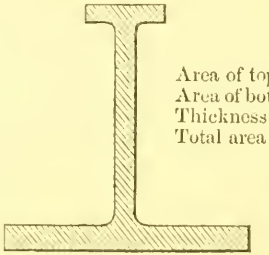
SECTION No. 1.

FAIRBAIRN'S EXPERIMENTS.			G. BERKLEY'S EXPERIMENTS (No. 1 Set). Being an Average of Two Experiments tried with Iron, of which Bars 2 in. × 1 in., placed on bearings 36 in. apart, bore 30 cwt. before rupture, and of which 1 sq. in. bore 10·25 tons in tension.			G. BERKLEY'S EXPERIMENTS (No. 2 Set). Being an Average of Three Experiments tried with Iron, of which Bars 2 in. × 1 in., placed on bearings 36 in. apart, bore 33¼ cwt. before rupture, and of which 1 sq. in. bore 11·75 tons in tension.			Dimensions of Girder Tested.
Weight in lbs.	Deflection in In.	Remarks on Fracture.	Weight in lbs.	Deflection in In.	Remarks on Fracture.	Weight in Tons.	Deflection in In.	Remarks on Fracture.	
11,186	·4	Breaking weight, 6 tons 9 cwt. 14 lbs. = 3,214 lbs. per square inch of section.	11,186	·166	Breaking weight, 10 tons = 4,977 lbs. per square inch of section.	4	·143	Breaking weight, 10 tons = 4,977 lbs. per square inch of section.	
12,698	·45		12,698	·190		5	·179		
13,706	·52		13,706	·210		6	·215		
14,462	..		Tons. 7	·245		7	·253		
			8	·290		8	·271		
			9	·338		9	·345		
			10			10	·391		

	Ins.		Ins.	Sq. Ins.
Area of top rib	= 1·6	×	·315	= 0·5
Area of bottom rib	= 4·16	×	·53	= 2·2
Thickness of vertical part				= 0·38
Total area of section				= 4·5

TABLE No. 7.—Experiments on Cast-Iron Girders—*continued.*

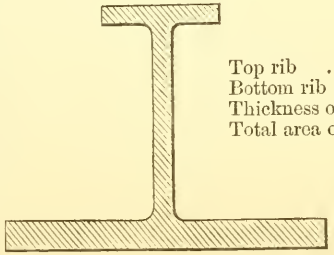
SECTION No. 2.

FAIRBAIRN'S EXPERIMENTS.			G. BERKLEY'S EXPERIMENTS (No. 1 Set). Being an Average of Two Experiments tried with Iron, of which Bars 2 ins. × 1 in., placed on bearings 36 ins. apart, bore 30 cwt. before rupture, and of which 1 sq. in. bore 10·86 tons in tension.			G. BERKLEY'S EXPERIMENTS (No. 2 Set). Being an Average of Three Experiments tried with Iron, of which Bars 2 ins. × 1 in., placed on bearings 36 ins. apart, bore 36 cwt. before rupture, and of which 1 sq. in. bore 13·3 tons in tension.			Dimensions of Girder Tested.
Weight in lbs.	Deflection in In.	Remarks on Fracture.	Weight in lbs.	Deflection in In.	Remarks on Fracture.	Weight in Tons.	Deflection in In.	Remarks on Fracture.	
8,288	·24	Breaking weight, 7 tons 9 cwt. 42 lbs. = 3,346 lbs. per square inch of section.	8,288	·128	Breaking weight, 11 tons 15 cwt. = 5,264 lbs. per square inch of section.	4	·145	Breaking weight, 11 tons 17 cwt. = 5,308 lbs. per square inch of section.	
12,698	·36		12,698	·200		6	·213		
13,706	·40		13,706	·217		7	·251		
14,210	·42		14,210	·225		8	·301		
15,218	·45		15,218	·242		9	·332		
15,722	·48		15,722	·252		10	·381		
16,226	·49		16,228	·260		11	·428		
16,730	.53		16,730	·270					
			Tons.						
			8	·292					
			9	·339					
			10	·387					
			11	·469					

	Ins.	In.	Sq. Ins.
Area of top rib	1·56 ×	·315	= 0·49
Area of bottom rib	5·17 ×	·56	= 2·89
Thickness of vertical part			= 0·34
Total area of section			= 5·

TABLE No. 7.—Experiments on Cast-Iron Girders—*continued.*

SECTION No. 3.

FAIRBAIRN'S EXPERIMENTS.			G. BERKLEY'S EXPERIMENTS (No. 1 Set). Being an Average of Two Experiments tried with Iron, of which Bars 2 ins. × 1 in., placed on bearings 36 in. apart, bore 30 cwt. before rupture, and of which 1 sq. in. bore 10·50 tons in tension.			G. BERKLEY'S EXPERIMENTS (No. 2 Set). Being an Average of Two Experiments tried with Iron, of which Bars 2 ins. × 1 in., placed on bearings 36 ins. apart, bore 38 cwt. before rupture, and of which 1 sq. in. bore 13·94 tons in tension.			Dimensions of Girder Tested.
Weight in lbs.	Deflection in In.	Remarks on Fractures.	Weight in Tons.	Deflection in In.	Remarks on Fractures.	Weight in Tons.	Deflection in In.	Remarks on Fracture.	
		Breaking weight about 11 tons 13 cwt., broke by compression = 4,075 lbs. per square inch of section.	4	·134	Breaking weight, 14 tons 5 cwt. = 4,988 lbs. per square inch of section.	4	·127	Breaking weight, 18 tons = 6,300 lbs. per square inch of section.	
			6	·198		6	·182		
			8	·264		8	·240		
			10	·340		10	·303		
			14	·553		14	·456		
						17	·654		

	Ins.		In.	Sq. In.
Top rib . .	= 2·33	×	·31	= 0·72
Bottom rib .	= 6·67	×	·66	= 4·4
Thickness of vertical part. .				= 0·266
Total area of section . . .				= 6·4

STRENGTH OF IRON AND STEEL.

The form of fracture is shown by dotted lines.

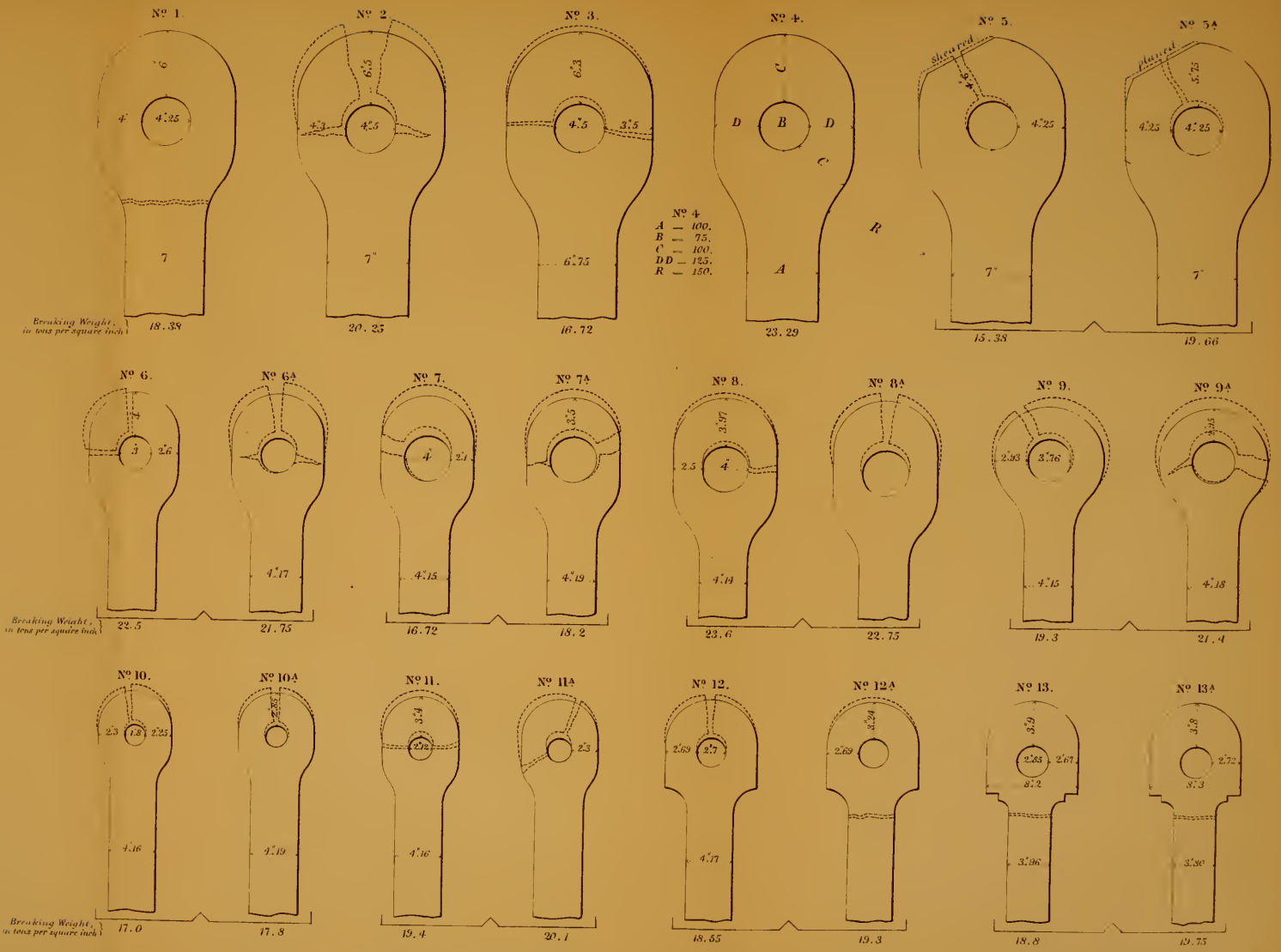


TABLE No. 8.

STATEMENT of TESTS taken WEEKLY from October 1869 to April 1870 (inclusive).

Deflection with 20 Tons.	Permanent Set with 20 Tons.	Deflection with 1 Ton falling 30 ft.	Specific Gravity of Steel in Rail.	Proportion of Carbon in Rail.	Tensile strength of Steel per square inches.
4 feet length of Rail. 3 ft. 6 ins. bearings.		4 ft. length of Rail, 3 ft bearings.			
In.	In.	Ins.			Tons. cwt. qrs. lbs.
·41	·13	$6\frac{5}{8}$	..	·42	38 0 0 0
·42	·22	$7\frac{1}{4}$	..	·32	38 12 1 8
·22	·02	$6\frac{3}{8}$	..	·47	41 19 1 4
·16	·00	$6\frac{7}{8}$	..	·38	42 8 0 24
·23	·08	$7\frac{3}{4}$	..	·36	37 14 1 24
·17	·00	$7\frac{1}{8}$	..	·37	41 14 3 8
·22	·04	$7\frac{3}{8}$	..	·38	40 12 2 0
·54	·37	$8\frac{1}{4}$	..	·38	33 16 3 4
·36	·19	$7\frac{1}{8}$	..	..	40 0 2 8
·42	·21	$7\frac{1}{8}$	..	..	39 10 0 20
·18	·02	$6\frac{1}{2}$	..	·35	43 10 2 4
·31	·16	7	..	·35	41 1 1 20
·35	·18	$6\frac{5}{8}$	..	·44	43 1 2 12
·24	·05	$6\frac{1}{4}$	..	·40	45 19 2 16
·17	·03	$6\frac{3}{8}$	7·852	·40	36 12 0 16
·17	·00	$5\frac{1}{8}$	7·852	·36	45 10 2 24
·21	·10	$6\frac{7}{8}$	7·865	·33	37 14 1 24
·18	·04	$7\frac{1}{4}$	7·848	·40	38 1 1 0
·17	·00	6	7·862	·37	40 16 3 24
·17	·02	$6\frac{1}{2}$	7·860	·34	43 1 2 12
·16	·03	$5\frac{3}{4}$	7·854	·38	43 19 2 6
·18	·05	$7\frac{1}{8}$	7·862	·39	44 8 1 24
·16	·02	$5\frac{7}{8}$	7·861	·43	44 3 3 20
·19	·05	$6\frac{3}{4}$	7·855	·41	39 10 2 6
·20	·05	$5\frac{7}{8}$	7·852	·35	39 5 2 24
·25	·13	$7\frac{1}{8}$	7·853	·40	40 3 2 8
·23	·10	$7\frac{1}{2}$	7·860	·33	37 18 0 4
·17	·03	$6\frac{3}{8}$	7·858	·43	43 15 0 0
·19	·04	$6\frac{1}{4}$	7·850	·35	41 5 3 16
·43	·20	$7\frac{3}{4}$	7·850	·35	37 18 0 4
·23	·09	$7\frac{5}{8}$	7·859	·35	38 16 3 4
·20	·05	$6\frac{1}{4}$	7·850	·41	41 10 1 12
·23	·11	$6\frac{5}{8}$	7·850	·38	39 19 0 12
·40	·17	$7\frac{5}{8}$	7·856	·41	40 3 2 4
·51	·29	$7\frac{7}{8}$	7·868	·37	35 14 1 4
·26	·09	$6\frac{7}{8}$	7·851	·35	40 12 2 0

Mr. G. Berkley explained that the figures marked 9 and 9A up to 13 and 13A (Plate 18) represented correctly the proportions of certain links which were employed in well-known bridges, though they did not represent the dimensions of those links. The experiments were all tried in duplicate, and he believed showed what the strength of such links of their full dimensions would be.

He desired to acknowledge the kind assistance which had been afforded him, at some expense, by Messrs. Howard and Ravenhill, and especially to thank the gentleman who represented them, Mr. Keeling, in trying various experiments. He also wished to acknowledge his obligations to the Anderston Foundry Company, for having made and tested a number of cast-iron girders.

Mr. G. H. Phipps said, he considered the Paper particularly useful to an engineer in drawing up specifications, where precise directions in a condensed form had to be given. On the theoretical question, as to the degree to which the limit of elasticity in iron might be approached with safety in actual constructions, he agreed with the Author of the Paper, that very little had been done in recent times to guide the practical man more satisfactorily than in times past; for notwithstanding the praiseworthy efforts to clear the question, as shown by the experiments recorded in the "Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures," by those of Sir W. Fairbairn and others, the limit of one-fourth the breaking weight, as the safe load in practice, seemed to be arrived at rather by guess than by any scientific deduction. So long ago as the year 1822, when the Menai bridge was being constructed, it was stated that the suspension links of the chains, each of $3\frac{1}{4}$ square inches sectional area, "were capable of bearing a strain of $87\frac{3}{4}$ tons before fracture; but at one-half of this strain, they showed elongation; and to keep within that strain or tension, it was judged advisable to limit the proof to 35 tons, being about 11 tons to every square inch of cross section."[1] Since probably about 6 tons on the inch was the strain to which the iron in the Menai bridge was ordinarily subjected, the measure would appear to be about the same as that in use at the present time.

Mr. Berkley's method for determining when the amount of stretching of any bar was such as to equal the true elastic limit of the iron, was based upon observing the time during the experiment when the elongations ceased to be uniform for equal additions of strain; and this he considered took place when about half the breaking strain was applied. This conclusion, however true it might be, threw no light on the rule of adopting half that strain only as the safe strain in practice.

With regard to the proper form for the heads and eyes of

[1] *Vide* 'Life of Thomas Telford,' 4to., London, 1838, p. 223.

suspension links, in relation to the sectional area of the body of the bar, the experiments recorded in the Paper showed the necessity for a proper proportion between the width of the bar, the diameter of the eye, the metal beyond the eye, and the two portions on each side of it; for if the eye was too small, the intensity of pressure of the pin against the iron became too great, and the iron on each side could not all come into action at once. If the eye was too large, there was a great transverse strain tending to break the iron through the crown, and also the practical difficulty arising from the excess of width in the head over the body of the bar. It must not be supposed, however, that no attempts had been made, prior to the present time, to ascertain the true proportions of suspension bars. Many experiments had been tried, under the direction of the late Mr. Brunel, to determine that point prior to the ordering of the iron for the Clifton and Hungerford bridges. He desired also to bear testimony to the valuable Paper on this subject by Sir Charles Fox, read before the Royal Society in 1865, where most of the present points were ably discussed, the Author having been led to experiment largely on the subject, in consequence of having to manufacture and test the links for the suspension bridge at Kieff, erected from the design of the President of the Institution, Mr. Vignoles.

Little additional information, relative to iron when used as struts under compression, had been acquired since the important laws of the strength of columns, referred to in the Paper, were first enunciated by Professor Hodgkinson, and were now generally accepted as data. Some of the most interesting experiments since then were those referred to by Mr. Barton, in his Paper on the Boyne viaduct.[1] These were also recorded in Mr. Stoney's work on "The Theory of Strains,"[2] and showed the great increase of resistance of comparatively slender bars used as struts, when connected by a system of light diagonal bracing. In the Paper the comparative merits of struts connected at their extremities, either by a single pin or by an assemblage of rivets, had been considered. He conceived that upon the same grounds that flat-ended columns were stronger than those with rounded ends, the rivetted connection was the more favourable of the two. All the experiments recorded in the Paper on the transverse strength of cast iron showed a large excess of strength over that obtainable by applying the ordinary rules of calculation, and by using the known tensile strength of the iron. This increase was, as was well known, the subject of a Paper by Mr. W. H. Barlow in the Philosophical

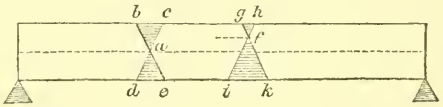
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 452, *et seq.*

[2] *Vide* "The Theory of Strains, &c." By B. B. Stoney, 2 vols. 8vo., London, 1866-69.

Transactions. but, so far as he was aware, the cause of the increase of strength had never been satisfactorily explained, for although it had been attributed to a movement of the neutral axis towards the compressed side of the beam, after the true elastic limit of the iron was passed, that fact taken by itself did not appear to afford a sufficient explanation.

It was shown by the experiments on bars of cast iron 10 feet long and 1 inch square, recorded by Mr. E. Clark,[1] that whilst the bars moved through the same range for compression as for tension during the application of moderate strains, as soon as these became considerable, so as to be close upon the breaking strain for tension, the amount of stretching became considerably greater than the corresponding shortening with similar strains. With 12,645 lbs. the stretching amounted to ·1488 of an inch; and with 14,453 lbs. the shortening amounted to ·1416 of an inch. Thus, at these considerable strains, each unit of the compressed material in the transverse section became of a higher value than an extended unit;

Fig. 1.



and therefore, while $b\ c\ a = d\ a\ e$, in Fig. 1, applied properly up to near upon the elastic limit of the material, it required to be changed into $g\ h\ f = f\ i\ k$ under the severe strain approaching the breaking point, where $g\ h\ f$, the smaller triangle, became of the same value as $f\ i\ k$, the larger, and f, the neutral axis, was elevated.

Mr. Callcott Reilly remarked that, in the opening paragraphs of the Paper, the Author had alluded to the limits of stress to which iron and steel might be safely submitted in practice, and although he had not mentioned the phrase 'limit of elasticity,' he had evidently had its meaning in his mind; and Mr. Reilly inferred that he had been somewhat puzzled to find a definition of it, and a mode of ascertaining it, that would be practically useful.

There were three kinds of simple stress to which a piece of elastic metal was liable, which were familiarly known as tensile stress, compressive stress, and shearing stress. Each of these simple stresses had, in every elastic metal, a limit of elasticity corresponding to it. In wrought iron, which was the most important material to constructors, the limit of elasticity of shearing stress had not, so far as he knew, yet been determined, and those of tensile stress and of direct compressive stress were generally

[1] *Vide* "The Britannia and Conway Tubular Bridges," vol. i., p. 385.

admitted to be equal, at all events for all practical purposes. As to the definition of the limit of elasticity, the oldest one was, that it was the greatest intensity of stress that could be produced on a section of the piece, without causing a permanent deformation or set; and he thought that definition to be perfectly true in a perfect piece of wrought iron. The second definition that had been adopted, made the limit of elasticity to be the greatest intensity of stress, for which the total deformation was directly proportional to the intensity of stress which produced it. That also he believed to be a perfectly true definition, and to correspond almost exactly with the limit as fixed by the first one. These two definitions had been adopted by all the recent French writers, and he thought on good grounds. Other definitions had been proposed by Wertheim and by Mr. Knut Styffe, of Sweden; but as they seemed to be founded upon arbitrary considerations, and Styffe's in particular would require a good deal of explanation to make it understood, he would pass them by. He would endeavour to explain why the two first definitions might, in his opinion, be trusted. Hodgkinson was the first in England to experiment on this subject, and his two series of experiments, on long wrought-iron bars, were those generally referred to for information. Those experiments were made by the extension of two bars, each 50 feet long, and each of them made up of several shorter pieces welded together. As the results of the two series of experiments were very similar he would only refer to one of them,—that given in the third edition of the *Résistance des Matériaux* (published in 1862) of General Morin, whose digest of these and other experiments was in a very convenient shape for reference. He would premise, that if the elongation of the bar was always exactly proportional to the tensile stress producing it, then the coefficient or modulus of elasticity of extension computed from those circumstances would be always the same; if not exactly proportional, then the coefficient would differ in the same proportion. Morin had computed the coefficient of elasticity for each increment of load applied by Hodgkinson; and by a comparison of those computed coefficients with one another, the variation of the rate of elongation could be very easily seen. In the following tables he had retained the metrical units of measure, because the absolute values of the numbers were of less consequence than their relative values, and because the tables could thus be more readily compared, with the more extensive series in Morin's work.

Table 1 (page 260) was an extract from Hodgkinson's experiments on the elongations of a long bar of wrought iron of the quality called "best." Comparing the coefficients of elasticity in the last column, rejecting the two first observations for reasons to be presently mentioned, it was seen that, within the limits of 5·6 kilos. and 15 kilos.

TABLE I.

HODGKINSON'S EXPERIMENTS on the Elongations of a BAR of best Quality of WROUGHT IRON, 15 Mètres long (= 49·2 feet), Section = 135·39 Square Mill. Each Increment of Load = 1·87429 Kilo. per Square Millimètre.

Loads per Square Millimètre of Section = P. Kilos.	Elongation per Mètre of Length.		Values of E the Coefficient of Elasticity $= \frac{P}{i}$. Kilos.	Mean value of $\frac{P}{i}$, of those bracketted.
	Total $= i$ Millimètres.	Permanent. Millimètres.		
1·87429	0·082	,,	22,824	
3·74930	0·185	,,	22,216	
5 62406	0·284	0·00254	19,824	Mean = 19,666. Greatest deviation of mean from any one value = 1·7 per cent. Difference between greatest and least = 2·5 per cent.
7·49456	0·379	0·00339	19,704	
9·37430	0·475	0·00424	19,729	
11·24813	0·571	0·00508	19,706	
13·12283	0·665	0·00677	19,714	
14·99720	0.760	0·01009	19,320	
16·87219 &c.	0·873 &c.	0·0330 &c.	19,320 &c.	

(The original table is continued up to rupture.)

per square millimètre—that was, from $3\frac{1}{2}$ tons to $9\frac{1}{2}$ tons per square inch,—the elongations were almost exactly proportional to the intensities of stress producing them; the greatest deviation of the mean value of the coefficient of elasticity from any one, being only 1·7 per cent., and between the greatest and least values $2\frac{1}{2}$ per cent.—deviations that might fairly be said not to exceed the possible errors of observation and the accidental irregularities of the material. So that, between those limits, the elasticity of wrought iron might be pronounced practically perfect, were it not for the appearance of the permanent elongations or sets in the third column of the table. It therefore became an interesting subject of inquiry to ascertain the cause of those permanent elongations. Now he believed with Morin and de St. Venant that those small sets which occurred within the limits of elasticity were accidental, and owing to the imperfect condition of the bar, and that they might be attributed to two causes: the first cause might possibly be the sinking of the point of suspension of the bar, which it did not appear that Hodgkinson took any notice of; and the second and more important cause might be, that the first application of each increment of the load would tend to straighten the bar, considered as a whole, and also to straighten the laminæ composing it, thereby equalising the intensities of stress upon the different fibres. It was for that reason that he rejected the two first observations, the loads then applied not being sufficient to produce any appreciable effect in straightening the bar; besides

which, the difficulty of exactly measuring such very small elongations rendered those two observations untrustworthy.

These conclusions had been verified in a remarkable manner by a series of experiments undertaken by General Morin, and made at the Conservatoire des Arts et Métiers at Paris, and he need scarcely say with the most minute care and accuracy. Abstracts of the results of those experiments appeared in Table 2 (page 262). They were made to determine the elongations and permanent sets of a long wire, of the finest charcoal iron—of course in one piece—polished and hardened by being repeatedly passed through the draw-plate. The wire was 25 mètres long, or about 82 feet, and 0·16 of a millimètre in diameter, or about 0·0063 of an inch. The object of choosing so small a diameter was no doubt to ensure the utmost practicable uniformity of structure. The hardening and polishing by cold-drawing might be held to have perfected the material, and to have raised the limit of elasticity to the highest practicable point—a well-known result of those processes.

It would be noticed that the greatest permanent set produced by the first series of experiments, although itself extremely minute, being only $\frac{1}{2976}$nd part of the total length of the wire, was nearly ten times greater than the mean of those produced by the second and third series of experiments; and it might, with considerable certainty, be said to be due entirely to the straightening of the wire, bearing in mind that the wire was taken from a reel or coil. In the second and third series of experiments the extremely small permanent sets observed were practically inappreciable, and might be justly considered as null, in comparison with the variations of length that would be produced by extremely small variations of temperature, which, however, was kept as uniform as possible during the experiments.

The effect of cold-hardening, in raising the limit of elasticity, was rendered very obvious by the third series of experiments, where it appeared that the wire supported a load of 600 grammes, producing a tensile stress of 29·84 kilogrammes per square millimètre, or 18·8 tons per square inch, without altering the elasticity of the metal.

It would be interesting to compare the mean value of the coefficient of elasticity of the metal of the wire with that deduced from Hodgkinson's experiments upon bar iron. Morin deduced its value as follows:

From the 1st series of experiments	E = 19,326	kilos.	per	sq. mill.
„ 2nd „	E = 19,747	„		„
„ 3rd „	E = 19,857	„		„
General mean value of	E = 19,643	„		„

TABLE 2.

ABSTRACT of RESULTS of Three successive Series of EXPERIMENTS on a WIRE of CHARCOAL IRON, unannealed, hardened, and polished by cold-drawing. Length, 25 Mètres (82 Feet); Diameter, 0·16 Mill. (0·0063 Inch).

	Loads. Initial Load = 123 Grammes. Constant Increment of Load = 50 Grammes.	Elongations per Kilogramme and per Mètre.	Difference of Length between Bench Marks after unloading, or permanent Set.
First series of Experiments.	Grammes. 50 100 150 200 250 300 350 400	Mill. 2·84 2·71 2·60 2·60 2·60 2·53 2·55 2·52 Mean = 2·565. Greatest deviation of the mean from any one = 0·035 mill. = 1·4 per cent. of the mean.	Mill. + 0·13 + 0·20 + 0·31 + 0·61 + 0·53 + 0·44 + 0·65 + 0·84 = $\frac{1}{29762}$nd part of the total length.
Second series of Experiments.	50 100 150 200 250 300 350 400	2·66 2·59 2·49 2·51 2·50 2·49 Mean = 2·54. Greatest deviation of mean from any one = 0·12 mill. = 4·7 per cent. of the mean.	+ 0·05 + 0·03 + 0·26 + 0·12 0·00 + 0·08 Mean = + 0·09 = $\frac{1}{277777}$th of the total length.
Third series of Experiments.	50 100 150 200 250 300 350 400 450 500 550 600	2·53 2·56 2·55 2·50 2·51 2·48 2·49 2·50 2·48 2·48 2·48 2·46 Mean = 2·5. Greatest deviation of mean from any one = 0·06 mill. = 2·4 per cent.	− 0·02 + 0·02 − 0·04 + 0·02 − 0·02 + 0·07 + 0·02 + 0·02 + 0·22 + 0·24 + 0·20 Mean = + 0·08 = $\frac{1}{312500}$th of the total length. Maximum = + 0·24 = $\frac{1}{104167}$th of the total length.

These showed a remarkable uniformity, and a still more remarkable agreement with the value furnished by Hodgkinson's experiments, viz.: E=19,666 kilos. per square millimètre. The difference was so small, that, for all practical purposes, the elasticities of the wire and of the bar might be pronounced identical, although the limit of elasticity of the wire was at least twice as high as that of the bar.

Similar experiments were made by Morin upon a much thicker wire, viz., 2·066 millimètres in diameter, but annealed, and with a similar result as far as respected permanent set; but the mean value of the coefficient of elasticity was shown to have been diminished by the annealing process to E = 15,763 kilos. per square millimètre. He also experimented upon wires of copper, with precisely analogous results.

The general conclusions from these experiments were, first, that wrought iron in a perfect condition exhibited no permanent set within the elastic limit, and that the apparent sets hitherto exhibited in experiments on bar iron were due to accidental irregularities of texture, which the process of repeated extension, between the elastic limit, tended to remove; and, secondly, that the limit of elasticity of extension of bar iron corresponded to an intensity of stress between 9 tons and 10 tons per square inch, and that in cold-hardened wire of fine charcoal iron it might extend to double that intensity.

Mr. W. Parsey remarked that, in his opinion, the strength for plates which Mr. Berkley fixed as being the practical limit was rather low; instead of 20 tons to the inch he thought 21 tons or 22 tons would be better; but as that involved a question of price for ordinary work the less strength might probably be sufficient.

In regard to the extension produced in a bar of iron or steel 12 inches long before breaking, it was important to state that the proportional amount of extension before rupture must be estimated on 12 inches of length, and no more, because a great portion of the extension took place by diminution of the diameter at the point of rupture, and only the same quantity took place from that cause in a bar which was 10 feet long.

In the course of numerous experiments on iron and steel of different kinds, he had come to the conclusion, that there was a point of strain under which they were perfectly elastic, and that under that strain there was no permanent set whatever. The first experiments he made were in the year 1857-8, and were generally carried out by scribing on the bars with a trammel, one end of which had a fine point and the other a fine chiselled edge. The trammels were 5 feet or 10 feet long. The bars were scribed when the strain was on, which showed the amount of extension, and again when it was taken off, to ascertain if there was any

permanent set, which would be shown if the first line drawn was made any thicker. Although these experiments were crudely conducted, they appeared to be corroborated by others more carefully made; and he thought, in most operations, they might be relied on as indications whether there was permanent set or not. He had subsequently experimented with more delicate instruments; and in all cases the instrument was attached to the bar direct, and there were no intermediate parts to disturb the results. He found that up to a strain of 8 tons or 9 tons to the inch in ordinary wrought iron, and in the better qualities, up to a strain of 10 tons or 11 tons, there certainly was no permanent set. With steel there was no permanent set under a strain of from 10 tons to 20 tons, according to the quality.

In considering the size of the pin in proportion to the bar in tension-bars, he thought consideration should be paid to the strains to which the metal was to be subjected. The metal would be extended in the greater portion of the bar, and be compressed at the back of the pin-hole by the pin. The conclusion had been pretty well arrived at, that wrought iron was extended and compressed in equal quantities by an equal amount of pressure on equal areas; therefore, if a tension of 10 tons to the inch was put on the body of the bar, not more compression than 10 tons to the inch should be imposed on the pin; because, if the iron in the body of the bar had acquired a permanent set under a strain of 10 tons per inch, the metal at the back of the pin would have a strain of 10 tons to the inch upon it, if the pin was of the same diameter as the width of the bar; but if the pin was less than the body of the bar, it would have a greater pressure upon it in an inverse ratio; consequently, the metal behind the pin-hole and the pin would be upset and compressed, while the metal in the body of the bar would be uninjured. Directly any motion took place in the pin-hole by the metal being upset, a forward motion of the pin followed, which immediately produced a resolved transverse force, which tended to open the iron at the back of the pin; and that, he considered, was the reason why so many of the ends of the bars opened, coupled with the fact that at the back of the pin-hole the metal was not so sound as in the body of the bar, because it was the fag-end. In practice, the proportions arrived at by Mr. Berkley gave very satisfactory results. It was difficult and inconvenient in many instances to get the pin more than three-fourths of the width of the bar in diameter, although he thought it ought, theoretically, to be as large. If a bar were made with the same quantity of metal at the sides of the pin as in the body, and if the metal was as good behind the pin as in the body, the fibre carried round instead of along it, and the pin was of the same diameter as the body of the bar, then he thought the head would be as strong as the body.

Mr. J. Cochrane said his observations would apply more to the manufacture of the structures in which iron was used than to the forms of the links. He understood Mr. Berkley recommended that in all kinds of girder work the rivet-holes should be drilled, as a means of getting better work. No doubt where there were many thicknesses of plates to deal with that was correct; but where there were only one or two plates, it would be found more expensive to drill the holes than to punch them. He did not think better results were obtained from drilling than from punching, provided the work was done well. He had taken a bar of Lowmoor iron 2 inches in width and $\frac{1}{2}$ an inch in thickness, and through it had drilled a hole for a $\frac{7}{8}$-inch rivet; and from a bar cut off the same piece of iron he had punched a hole $\frac{3}{4}$ of an inch in diameter, and then drilled it out to the size of that drilled for the $\frac{7}{8}$-inch rivet. In another bar of iron from the same piece he had punched a hole for a $\frac{7}{8}$-inch rivet, as in making girders. From experiments with these bars he found that, taking the total strain which each bar carried, the bar with the drilled hole sustained 235 cwt., while the one that had been punched and then drilled supported 245 cwt., and that which had been only punched carried 226 cwt.; but looking to the area broken previously to the load being put on, the drilled hole sustained 494 cwt. per square inch; the punched and drilled hole 510 cwt., and the hole only punched, 490 cwt. Practically, therefore, one was as strong as the other. The strain was applied by hydraulic pressure, with a delicate gauge attached, the bars being pulled in the direction of their length. The next experiments were made with hard crystalline iron. The drilled hole carried 250 cwt., the hole punched and drilled 250 cwt., and the punched hole 244 cwt.; while the strain per square inch of area reached, with the drilled hole, 463 cwt., with the punched and drilled hole, 463 cwt., and with the punched hole 474 cwt. In another experiment he took three bars a little longer, and made three holes in each: one drilled, one punched and drilled, and one punched only. In all cases the bar broke at the punched hole; but it was remarkable that the hole which was punched and then drilled, retained its form as nearly as could be measured; whereas in the case of the drilled hole it became elongated. From that he deduced that there was no advantage, as far as strength went, in drilling over punching, or in punching and drilling over punching only.

In another set of experiments with ordinary good iron—such as an engineer would be satisfied with for girders—the results were much the same as in the previous cases. The drilled hole supported a strain of 427 cwt. per square inch, the punched and drilled hole 433 cwt., and the hole punched only 431 cwt. These trials were all made with the strain in the direction of the length

and in the direction of the grain. The bars were of uniform width before the holes were drilled and punched, but in all cases of punching the bar swelled out a little sideways. In a further experiment, with the iron pulled in the direction crossway of its length, the drilled hole bore 363 cwt., the punched and drilled hole 363 cwt., and the punched hole 374 cwt. per square inch of area. These results all tended to show, that it did not matter whether the rivet-holes were drilled, or punched and drilled, or punched only.

Mr. G. B. Bruce said, he thought the tendency amongst engineers was to refine a little too much in their mode of carrying out such works; and he believed they would find in practice the results to be, under ordinary circumstances, as Mr. Cochrane had stated. It was very necessary to know something about the circumstances under which experiments were made, and the machinery with which experiments were conducted. He had frequently found, that experiments made at the works of manufacturers, with the machinery they had and the appliances at their disposal, were very much at variance with the experiments made upon the same materials by independent persons laying themselves out specially for that work, with machinery specially prepared for it. No doubt it required great accuracy in measuring the dimensions of bars, whether tested for transverse strain or tensile strain. This was seldom carefully noted by the manufacturer. Therefore, if the experiments of Mr. Berkley had been made entirely under those circumstances, he should feel some hesitation in receiving it as an ascertained fact, that ordinary cast iron, used in the manufacture of sleepers, would bear a tensile strain of 13 tons and upwards per square inch. He was rather disposed to think that in Mr. Berkley's experiments, as in his own, there were contingencies in the mode in which they were carried out which would considerably affect them; and it would probably be found, that the older experiments, which put the tensile strength of cast iron at a lower figure, were more correct. The bulk of the machines he had seen indicated the tensile strain exerted in such a way as to take no cognisance of the friction upon the ram and other circumstances connected with the machine itself. That was not the case with the machines of Mr. Kirkaldy, and he thought that, to a certain extent, accounted for the differences between the experiments carried on at the manufactories and those conducted by Mr. Kirkaldy.

It was an extraordinary fact, that the test-bars which Mr. Berkley referred to as being 2 inches by 1 inch in section, when tested transversely with a weight upon them in the centre, always bore most when tested in the position in which they were cast; those bars being broadest at the top instead of at the bottom, and having most metal at the top instead of at the bottom. The natural conclusion would be, that if they were turned they would

bear more than when tested with the broad side up; but his experience agreed with Mr. Berkley's, that there appeared to be at least 16 per cent. more strength if they were tested theoretically the wrong way than if they were tested the right way; he made it about 20 per cent. gained. Allusion had been made by Mr. Berkley to the high strain borne by the bars which were cast with a view of testing the quality of the iron of which cast-iron sleepers were made. He, on the contrary, got the sleepers which would bear the blows of a hammer, or a falling weight, best, when cast from iron which would not bear so heavy a dead strain on the bars. In Scotland, he had no difficulty in procuring bars to bear a weight of 30 cwt., whilst the sleepers themselves broke under a blow of more than $3\frac{3}{4}$ cwt. falling from a height of 6 feet. When the cast-iron sleepers were procured from the Tyne, the bars supported with difficulty a weight of 28 cwt., whilst the sleepers cast from the same metal withstood the blow with a fall from the height of 9 feet; so that there was danger of this dead-load test being carried too far. Sleepers could be obtained which would stand better, as far as blows went, without using so high a bar test as Mr. Berkley had alluded to.

Mr. Kirkaldy had made some careful experiments for him to test the effects of a sudden reduction in the section of a bar of iron. The experiments were not very numerous, but they showed that the elastic limit of the iron was not affected by this change of size, although the ultimate strength was; and further, that a fibrous and soft quality of iron or steel was not affected to the extent that a more crystalline iron was by the same manipulation. In fact, superior, strong, tough iron did not show any reduction in the ultimate strength due to the change of form.

Mr. Bramwell asked whether the bars operated upon by Mr. Cochrane in the way he had described were got by shearing a plate, or whether they were portions of bars only.

Mr. Cochrane replied that they were bar iron, with the exception that the last experiments were made upon a portion of a plate, punched out, and the edges planed.

Mr. G. J. Morrison remarked that Figs. 5 and 5A (Plate 18) represented bars which had been weakened by having a little piece taken off the end, one sheared and the other planed. He was astonished at the great difference in the strength of those two bars, the one bearing only 15 tons per square inch of area of the bar itself, and the other 19 tons. He thought shearing was very like punching, and planing like drilling, and that those two bars would more or less accurately represent the relative strength of similar girders, one with punched holes and the other with drilled holes; consequently it would be more economical to have the holes in girders drilled, though the cost of punching was less. As a great deal

depended upon the testing machinery, he should like to know what machinery these experiments were made with. Mr. Cochrane said that in his experiments the strain was taken with a hydraulic ram and a delicate gauge. There was no reason to doubt the delicacy of the gauge, but it was questionable whether experiments made with a ram and the strains taken by a gauge could be worth much.

Mr. C. W. Siemens observed that the Paper contained a great deal of valuable practical information; but he considered enough had not been said, on the one important question which had been raised, viz., whether or not there was a definite limit of elasticity in metals. It was stated in the Paper, that a bar of iron 1 inch square would elongate with a strain of 3 tons to the inch, and would, on the load being gradually increased, continue to elongate up to a strain of 9 tons or 10 tons to the inch, beyond which point it was known that a more rapid rate of elongation commenced. These results seemed to imply that there was no definite limit where permanent elongation was produced, but in following up this argument the evident conclusion was, that the bar of metal of 1 square inch, if exposed for a great length of time to the moderate strain of 3 tons, must continue to yield, in the same way as though its elastic limit was really exceeded, and must ultimately yield to that force. But all experience went directly against such a supposition. One of the most perfect experiments that could be tried on that point might be found in the old cathedrals of Italy, where heavy chandeliers weighing $\frac{1}{2}$ a ton, or more, had been suspended for hundreds of years, by long rods of not more than $\frac{3}{4}$ of an inch in diameter. If any permanent injury was produced by such a load, it would no longer be safe to go into those buildings; and the heavy chandelier in the Pisa cathedral, which swung suggestively above the head of Galileo Galilei, must inevitably have long since fallen to the ground. He thought practically that no one had any belief in any such action of time, but he was not disposed, on the other hand, to condemn such experiments as those of Hodgkinson and Fairbairn. Possibly it might be the case that, in subjecting a bar for the first time to a strain, elongation did take place, which might be explained in this way: it was conceded that in the manufacture of a bar of iron internal strains must arise, owing to the different action of the rollers upon different portions of the material, and such "virgin" bar might be regarded as consisting of a number of aggregate fibres of metal strained one against the other, the internal metal, which had been the hottest, being permanently in tension, and the external metal in compression. In subjecting such a bar to a moderate strain, only the internal fibres would be permanently elongated, while the external metal would be simply released from compressive strain, after which all parts of the bar would bear the strain equally,

and this equalising of the active forces must necessarily be accompanied by a moderate stretch. Therefore, in order to ascertain the true limit of elasticity of a material, the first experiment upon a virgin bar should not be taken, but the strain should be continued till it had reached a certain moderate limit, when it should be reduced, and then the same series should be gone through again. In proceeding thus he thought it would be found that there was no permanent elongation till the true limit of elasticity was reached. This true limit of elasticity he regarded as being a very important point. Mr. Phipps had justly remarked that, in the long series of experiments on breaking strains, published by various authors, a conclusion was arrived at, more by guess than by scientific reasoning, to the effect that a load might be applied to, say, one-fourth of the breaking strain, with tolerable safety, without any distinction being made regarding the limit of elasticity of the particular material under examination. It would be found, however, that two bars of metal, which might break at nearly the same point, and which might consist, chemically speaking, of nearly the same materials, would be capable of bearing with safety a very different load. The one might begin to elongate with less than one-half the breaking strain, and the other would not begin to elongate till two-thirds of the breaking strain had been reached. He had made some experiments with cast steel, which, being the most refined and uniform metal, was best adapted for such experiments, proving these discrepancies according to the mode of its production; and he had no doubt that similar results would be obtained with iron, though it might not be so easy always to obtain the same degree of regularity with that material. He thought that the limit of elasticity of a material was of much greater practical importance to engineers than its ultimate breaking strain; because a structure was safe if no part of it was loaded past the point of limit of elasticity, but must ultimately fail if that limit was exceeded.

Mr. J. B. Redman commended Mr. Berkley's attempts to fill up the gap caused by the great absence of results of experimental research in the published works of the profession. Mr. Kirkaldy's work on Iron and Steel, however, contained an exhaustive memoir of all that had been done from the year 1762, when Muschenbroeck's experiments were published, and thence downwards.[1] Many of the results arrived at by Mr. Kirkaldy bore upon those recorded by Mr. Berkley. He thought Mr. Kirkaldy's experiments first directed attention to, and explained some apparent anomalies connected with breaking strains; and established the fact of the

[1] *Vide* "Results of an Experimental Inquiry into the Tensile Strength and other Properties of various Kinds of Wrought Iron and Steel." By D. Kirkaldy. 8vo., 2nd edition, 1863.

contraction of sectional area, coupled with the elongation of wrought iron when subjected to strain; as well as showed that the apparent anomaly of metal of inferior quality bearing apparently greater strain vanished at once, from the fact that finer material elongated and broke, presenting a much smaller comparative sectional area, the original area alone being considered by early experimenters. Those experiments bore so completely on the subject under discussion, that he should have been sorry if the labours of Mr. Kirkaldy in this direction had been allowed to pass without recognition.

Mr. W. E. Rich said it appeared to him, that the Author had designed a model link end, without consideration of the thickness of that link, with which the diameter of the pin had much to do. He believed that such a link as No. 3, up to about 1 inch thick, would give way by direct tension in the case of an outside link of a suspension-bridge chain. It would give way next by shearing; but beyond that, bending action came into play, and with a thickness of about $1\frac{1}{2}$ inch it would have a tendency to fracture under a bending action. He had found, on more than one occasion, a round pin broken where shearing action did not account for it, and the evidence was that it was rather due to bending.

Mr. R. P. Brereton said, with regard to the question of permanent set in iron, he had experience as far back as thirty years ago in suspension links for bridges built by Mr. Brunel, including those of Chepstow and Saltash, which embraced a very large number of links. It was believed that iron could be strained up to about 10 tons per square inch without permanent set, properly so called; and the specifications of both those bridges were framed accordingly. Very few of the links, which were tested to 8 tons to the square inch, bore out strictly the requirements of the specification. The calculation was that they would stretch about $\frac{1}{1200}$ part of their length; but they did not stretch so much as was estimated by about one-half. Nearly all retained a permanent set of about one-half what they originally stretched. These links were from 16 feet to 24 feet long, 10 inches, and 7 inches wide, and 1 inch thick. The shorter ones should have elongated about $\frac{5}{32}$ of an inch, but they stretched only about $\frac{3}{32}$ of an inch; and three-fourths of the number tested retained a permanent set of about $\frac{1}{32}$ of an inch. To ascertain that this did not injuriously affect the links, many of them were tried a second time, and it was found that no further permanent set took place. It was presumed that this arose, in some measure, from the thorough straightening of the link and the perfect bearing that ensued at the eye when the strains were first put on, and was not to be considered as impairing the strength of the link.

Attention had been drawn to the Hungerford bridge and

the Clifton bridge links. These were designed, thirty years ago, for the former bridge, and were 7 inches wide, 1 inch thick, and 20 feet long. The proportions arrived at, for the head and eye, were determined from experiments; and, notwithstanding they were shown in Mr. Berkley's table to be nearly the weakest, he thought, if a greater number of experiments had been made, different conclusions would have been arrived at. There were only two examples given of what purported to be the Hungerford bridge links, viz., Nos. 12 and 12A; but they were to a smaller scale, and were models only of the full-sized link, and it turned out that one, even of these experiments, showed the head to be in proper proportion; and the link broke, as it should have done, across the shank and not at the eye or shoulder. The proportionate size of the pin adopted thirty years ago was $\frac{2}{3}$ the width of the bar or shank. The experiments were made by increasing gradually the diameter of the pin, till such a size of head was attained as to break the link fairly in the shank. Pins of a size less than $\frac{2}{3}$ the width of the bar broke the link, by abrading or upsetting the surface of the eye against the pin; and it was further found that the eye behind the pin and at the sides should be increased, so that the section exceeded, to some extent, the shank or bar.

It would be seen that the link recommended by Mr. Berkley, was nearly similar to the links used at the Hungerford and the Clifton suspension bridges, as the metal of the enlargement of the shoulder happened to include the curve of shoulder suggested. They were therefore, as far as the shoulder went, practically the same. The model link which was broken did not give way by breaking at the shoulder; but the swelled out shoulder was put on the links at the Hungerford and the Clifton bridges for other objects than mere strength. In those days it was thought desirable to have means of taking out the pins and disengaging the links, for facilities of erection and to see whether they were properly fitted; and the additional metal was put in at the shoulder, so as to be laid hold of by clamps, in order to remove any particular links that were required. The Hungerford and the Clifton links coincided with Mr. Berkley's link as nearly as possible, at the point where injury, if there were any, would have occurred. He thought if Mr. Berkley had sheared off the projecting shoulder the links would have been alike.

In designing links ten years later, for the Chepstow and the Saltash bridges, other experiments had been made, which led to the belief that strength depended more upon the shape of the shoulder than upon excess of metal about the eye; and the result was, that the curve of the shoulder was considerably increased—the radius being as much as $7\frac{1}{2}$ times the width of the shank—with the object of deflecting the lines of strain along the shank as gradually as possible, before passing through the eye and

round the pin, which was essential when the strains were suddenly applied.

The proportions arrived at were:—

	Mr. Berkley's Link.	*Saltash Link.*
Bar or shank . . .	1·00 A	1·00 A
Diameter of pin . . .	·75 B	·66 B
Sides of eye . . .	1·25 DD	1·21 DD
End of eye	1·00 C	·60 C
Radius of shoulder . .	1·50 R	7·60 R

An American engineer was now engaged in building a bridge over the river Missouri, at St. Louis, in which steel was being used to a larger extent than had ever been done before. The arches were of 515 feet span, with a radius of 660 feet; the arches at Saltash being of 450 feet span, with a radius of 900 feet. The engineer was adopting steel columns only 9 inches in external diameter and 1½ inch thick, used in groups, to form the ribs or supporting arches. It was calculated that these steel arches might be loaded to 12 tons or 15 tons to the square inch with safety; and it was found that steel would sustain a pressure of 35 tons or 40 tons per square inch before the elastic limit was impaired. He looked to the results of that structure with great interest, as being, he believed, the largest arch ever constructed in metal; and it would determine the question, whether it was safe to use steel, with strains approaching to 20 tons to the square inch, with columns of so small diameter as 9 inches.

Mr. Phipps inquired whether the links of the Saltash bridge were tested as bars?

Mr. Brereton replied that none of the Saltash links were broken. If any were broken it was for experiment. They were tested to ascertain the permanent stretch that would take place under a strain of 8 tons to the square inch.

Sir Charles Fox said, few persons had paid more attention to the subject of links and pins of chain bridges than Mr. Brereton; and he was interested to find that Mr. Brereton's observations agreed with the results which he had given in a Paper presented to the Royal Society in 1865,[1] as to the comparative dimensions of the diameter of the pin and the width of the body of the link. Mr. Berkley, in his tables, gave the width of the link as representing 100, and the diameter of the pin as 75. Mr. Brereton gave 66 for the pin, and he believed the latter to be right.

Many years ago, Mr. Vignoles had entrusted to the firm with which he was then connected, the construction of the chains for the Kieff bridge over the river Dneiper. It was a large undertaking; the links weighed 1600 tons, and if they had been laid out touching one another they would have extended a distance of

[1] *Vide* Proceedings of the Royal Society of London, vol. xiv., p. 139.

over 17 miles; therefore it was of the greatest importance that the links and pins should be constructed upon right principles, and with that feeling his firm erected a hydraulic proving machine, of sufficient power to tear in two links of the width of 10¼ inches by 1 inch thick in the body. The pin-hole was 4½ inches in diameter, and no doubt that size had been determined upon, with the view of having metal enough in the pin to prevent its being sheared by the link. The difficulty to be overcome in the chains of bridges was that the pins should not interfere with and destroy the links. In the case of the Kieff bridge, the links were made by Messrs. Thornycroft of the best mixture of irons known, with a large proportion of Indian pig iron. From a number of experiments made on the iron—on pieces of 1 inch square—it was found that the bearing weight was 27 tons, and from that result he calculated that the links would sustain a strain of 270 tons. It was, however, found that with a 4½-inch pin none were equal to a strain of more than 180 tons. Experiments were then tried upon links of a larger section, viz., 3 inches wider in the head than the dimensions given in the contract drawing, but with the same size pin-hole. On proof, they bore no more strain than the others, and the conclusion therefore come to was, that the breaking of the head of the link was produced by the operation of tearing. He then took another link, with a number of transverse and longitudinal lines described upon the head, and, beginning with a strain of 5 tons to the square inch, and continuing up to 10 tons, he took tracings of the lines as bent by the various strains, and found that the pin was gradually moving upwards in the link, making the hole pear-shaped, and was undoubtedly seeking for a larger surface to bear against. He then took another link, and bored the hole out from 4½ inches to 6 inches in diameter, leaving the size of the link the same. He found that the strength of the link was thereby considerably increased, though it was really cutting away a portion of the head of the link; and from a number of experiments made on that occasion he came to the conclusion, that if it was wanted to break the straight part of a link 10 inches wide, the pin must be of such a diameter that the bearing surface in the hole of the link should be equal to the cross section of the link to be torn in two; accordingly, the right size of pin for a link 10 inches wide would be about 6½ inches. Till he used pins of that size he found it was impossible to tear a link in two in any other part than in its head. In the Paper previously referred to he had said:[1]

"That as the rule for arriving at the proper size of pin proportionate to the body of a link may be as simple and easy to remember

[1] *Vide* Proceedings of the Royal Society of London, vol. xiv., page 143.

as possible, and bearing in mind that from circumstances connected with its manufacture the iron in the head of a link is perhaps never quite so well able to bear strain as that in the body, I think it desirable to have the size of the hole a little in excess, and accordingly for a 10-inch link I would make the pin $6\frac{2}{3}$ inches in diameter instead of $6\frac{1}{2}$ inches, that dimension being exactly two-thirds of the width of the body, which proportion may be taken to apply to every case.

"As the strain upon the iron in the heads of a link is less direct than in its body, I think it right to have the sum of the widths of the iron on the two sides of the hole 10 per cent. greater than that of the body itself."

In ordinary cases, where the iron was of equal thickness—by which he meant where the head of the link was of the same thickness as the shank—it was in his opinion necessary that the diameter of the pin should be $\frac{2}{3}$ of the width across the body of the link, and that if made of smaller dimensions it would be impossible to break the body of the link.

Mr. G. Berkley, in reply upon the discussion, said, Mr. Parsey had stated that the heads of the links referred to were the fag-ends of the bars; the fact was, however, that sufficient length was always cut off from the ends of the bars to insure the head of the links being nearly as good as the bar. He admitted that experiments ordinarily tried at the works of manufacturers might not be perfectly reliable, but those he had brought forward had a special value, inasmuch as they were made on the material which was daily employed in practical operations. A large number of experiments were also of value in eliminating errors. The description of machine used by him was a dead-weight lever machine, the accuracy of which was tested in his presence on more than one occasion, by weights which had been proved to be true at the Government Standard Weight Establishment, where the weights and measures of manufactories in all large towns could be tested.

The exact size of the bars was measured to the $\frac{1}{1000}$th of an inch, and the exact strain upon the bars of 2 inches by 1 inch was accurately ascertained. When between eleven hundred and twelve hundred tests of a material, which was daily supplied for practical purposes, were thus obtained, he thought the information was more reliable and valuable than the individual experiments of any expert.

Mr. Vignoles, President, expressed the satisfaction he felt at the observations made in the course of the discussion, which so fully confirmed the correctness of the conclusions drawn from the experiments made for him by Sir Charles Fox twenty-five years ago.

May 10, 1870.

JOSEPH CUBITT, Vice-President,
in the Chair.

The Discussion upon the Paper, No. 1,279, "On the Strength of Iron and Steel, &c.," by Mr. G. Berkley, was continued throughout the evening.

May 17, 1870.

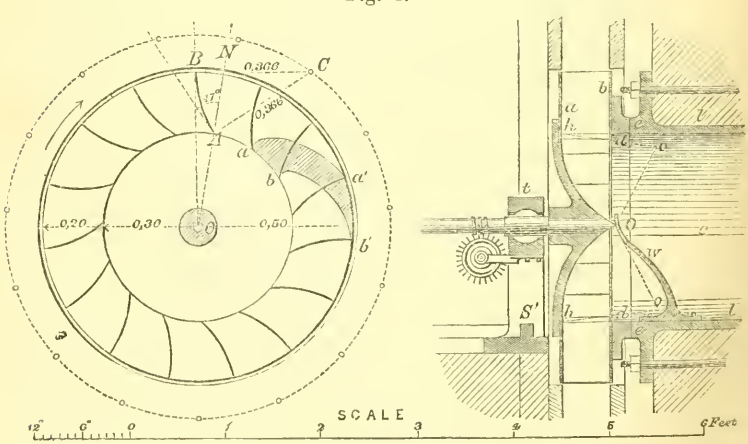
CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

No. 1,276.—"On the Conditions and the Limits which govern the proportions of Rotary Fans."[1] By Robert Briggs, of Philadelphia, U. S.

The recent attempt to employ rotary fans for the ventilation of mines in Great Britain, and the publication before a kindred Society of some examples in present use, render it possible that the results of an investigation made twelve years ago in America, and an account of the practice which has followed, may prove of interest to the members of this Institution, and through them to mine operators and to architects engaged upon public buildings.

As a preface to these remarks, it may be stated that the technical discussion of the subject has already been entered upon by eminent scientific writers. The theory and practice of the turbine water-wheel has been discussed, with its reversed application to the centrifugal pump, by numerous authors, including two German writers, Redtenbacher and Rittinger (Fig. 1), two French ones,

Fig. 1.

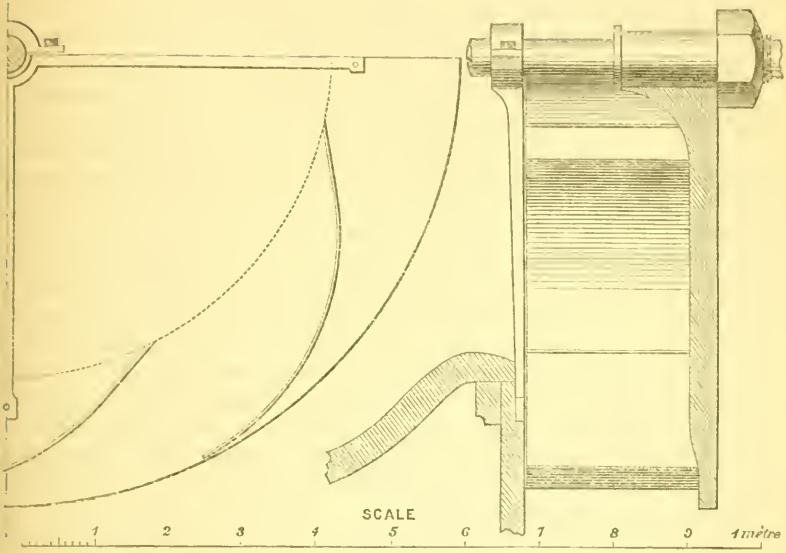


Rittinger's Fan.

[1] This Paper was read on the 22nd of March, 1870, but as the discussion upon it took place at this Meeting, the Paper and the discussion are printed consecutively.

MM. Combes (Fig. 2) and Péclet, and that distinguished English

Fig. 2.



Combes' Fan.

amateur mechanic, the late Mr. Appold; all of whom have studied and thrown more or less light upon the matter. Besides this, the practice of some intelligent constructors of fans has, during the past ten years, approximated towards an acknowledgment of the conditions and limits which will now be endeavoured to be stated more definitely than it is thought they have heretofore been; and it will be essayed to make these statements without resorting to any extended mathematical demonstration.

A rotary fan consists primarily of a certain number of tubular passages, which are rotated about a lineal axis at right angles to the direction of the passages, whereby a given volume of air, impelled either by centrifugal force, or by the shape given to the tubular passages radially, is moved at a determined pressure. In other words, it may be conceived that a shaft revolves, upon which is placed a disc or a set of arms, to which disc or arms some blades or vanes are attached, the zone of blades or vanes having sides or casing, either in close proximity to the edges of the blades or vanes, or attached to and made to revolve with them, and then the area enclosed between any two blades or vanes and the sides or casing may be considered as a tubular passage with an entrance at the centre of the fan and an exit at the periphery. M. Péclet

has used a course of reasoning which is thought to be original with him, but it will be carried further. He has said, "It is demonstrable, in mechanics, that if a tube A B, cylindrical, and completely open at its two ends, turns around a line O, perpendicular to its axis, the air escapes by the extremity A of the tube with a velocity equal to the velocity of rotation at this extremity. The velocity of escape is the same whether the tube is more or less long, provided the distance A O remains constant; it is still the same when the tube is curved. If we suppose that the orifice A be closed, in all cases possible, the pressure exerted by the air against the interior surface of the partition (cloison) will be equal to the height of air corresponding to the velocity of rotation of the point A."[1] This reasoning, based upon the tube example, can be extended, first, to a tube closed at the axial end and open at the periphery, when the partial vacuum will correspond to that due from the velocity of a body of the density of the atmosphere at the time, falling with the velocity at which the extremity moves; and, secondly, if the tube were closed at both ends, whatever might be the density of the enclosed atmosphere, the pressure on the axial end would be less than that on the outer end, by that due from the velocity of a body of the density of the enclosed air falling with the velocity at which the extremity moves.

Hence, whatever the shape of the vanes of a fan, its maximum pressure or suction involves no delivery whatever; and assuming a fan to be so proportioned that no regurgitations take place as the blades pass any point in the case, then such a fan will consume no power when it is closed, either at the inlet or the outlet, or both, for it is performing no work. The condition is that of a fly-wheel at a uniform velocity, or a ball governor with the balls spread to running position.

Now the pressure attainable by any rotary fan is exceedingly low when considered in pounds per square inch. A pressure equivalent to a column of water of 14 inches or 16 inches gives velocities dangerously near the strength of materials of which fans are constructed, in resisting centrifugal force, while a column of 7 inches or 8 inches of water is attainable only at very high speeds. In fact, a pressure or suction of 3 inches or 4 inches is nearly as large as can economically be attained in delivering a quantity of air, when the friction of machinery at high velocities, the want of adhesion of belts, and certain other considerations of friction of air on the vanes (which will be referred to further on) are accounted for. Thus, the largest differences of pressure are less than the ordinary atmospheric disturbances, as indicated by the barometer.

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[1] *Vide* "Traité de la Chaleur Considérée dans ses Applications," par E. Péclet. 2e édition. Tome premier, f. 217e par. 533e. Paris, 1843.

It is possible to construct a series of fans, following from one to the other, and to increase the pressures by repeated efforts; and this method is applicable to many purposes, where the volumes to be moved are beyond the scope of a pump, and the pressure yet relatively low to that obtained from pumps. So far as volume is concerned, a very small fan represents the largest blowing engines at blast furnaces.

This limit of efficiency as regards pressure is the first limit of a rotary fan.

The rotary fan when at work is in a bath (as it were) of air; the action of the blades upon the fluid produces a current of a certain velocity through, first, the central openings of the opposite sides of the case, then along the blades (escape sideways being prevented by the case), and the air is delivered at some other definite velocity at the periphery of the blades. Whilst this movement of air is going on, there is a relative excess of pressure or tension in the air at the point of exit from, as compared with the pressure or tension at, the point of entrance to the fan. The blades are the effective means by which the air is impelled, and the real performance of work by a fan begins with the blades at the point where the air first reaches them, and ends with them at the periphery when the air leaves them. The terms pressure on the one hand, and suction on the other, therefore, merely express one and the same force. It has already been shown, that they do not differ as much as the atmosphere does in two days, so that whether the outlet of the fan, or its inlet, is connected with a duct, passage, chamber, or shaft, the suction fan of the most economic proportions is still identical with the blast fan, also best adapted for the performance of duty. This condition must be regarded as one of the highest importance in simplifying the study of the fan question. It was the want of recognition of it that led M. Combes to the form he has described in his 'Aérage des Mines.' He assumed that a fan for suction should deliver its air at the lowest possible velocity from the blades, and obtained as a result a fan of large dimensions, and an arrangement of blades to perform the least possible work, where the high angular velocity gave the opportunity of performing the most work.

Suppose it is desired to move a certain quantity of air in a fixed time under some definite resistance; if the air has for the time imparted to it a velocity which equals the resistance, the problem is solved. The first element in this proposition is the quantity of air which is to be induced to enter the fan, by the action of the blades in removing from before it other air which has been intercepted by them. The ring of inner edges of the blades therefore constitutes an area or duct for the entrance of new air to be acted upon, and the entrance of air to the fan at the

sides (or the circular openings in the case) should be so large, that the air can reach the inner edge of the blades without a previous resistance of passage through a smaller opening. This condition limits the width of a fan at the front of the blades, as compared with the diameter of the two central openings, to one-half that diameter. Having got the air fairly in contact with the blades, it is possible by altering the shape of them radially, that is, the angles which the blades make with the radii at different points, to have a demand of area of each concentric ring outwards from the inner edges of blades as shall call for specific widths at the given diameters of such rings.

But the propositions that the fan of suction is that of blast, and that the terms suction and pressure are interchangeable, imply and carry with them the conclusion, that the action derived from the shape of the blade should be the same on the entering air as on that leaving the fan. This condition, however, is only incident to the particular shape of blade, where the angle of the blade at any point is constant with any radial line at that point—in other words, when it is a logarithmic spiral. This angle may be from 0° to 90°, that is, from a straight line. to the impossible case of a series of concentric circles; but the shape will insure each part of the blade giving an impulse to the air in contact with it, proportionate to the velocity of that point round the axis. Taking this form of blade, and admitting or supposing the air to be really impelled with velocities proportionate to the radial distances from the axis, then the area of each concentric ring should diminish as the radii increase in length.

Let d = the diameter of the mouth of the fan on both sides,

and $\frac{d}{2}$ = the co-ordinate at d.

Let D = the diameter of any point where it is desired to find the co-ordinate y, which shall give the area of the rings of that point to vary in the inverse ratio of the radial distances for other values of D.

$$\therefore \; y = \frac{d^3}{2\,D^2}.$$

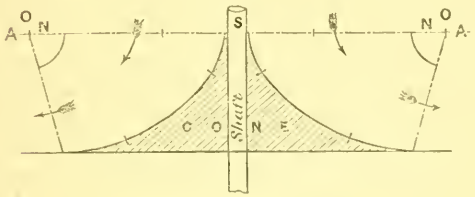
At the entrance of a fan the direction of the currents of air is, of course, at right angles with the plane of rotation; and in the case of the ordinary fan taking in air at both sides, the two entering currents are directly opposed to each other. In the centre, between the currents, there may be inserted a conoid, so shaped that each particle of air shall preserve its uniform velocity, and be gradually diverted into the direction desired. The shape of the mouth then becomes such, in half section, that the surface

areas of the conical frustra on the base A A of A, B, C, D, E, are equal (Fig. 3). In actual construction this is somewhat modi-

Fig. 3.

fied (Fig. 4). A central shaft S has to be supposed as the axis

Fig. 4.



of the fan; the corners N provide a reasonable allowance for the air to change its direction upon (where the larger volume passes, at the periphery of the mouth); and the surface of the cone thus indicated becomes in terms of x and y, the origin being on the line A A, and x commencing at 0,

where r = the distance from the centre of the shaft to 0,

a = the radius of the shaft or boss of the cone at the line A A,

and n = the radius of the circular newel < N >;

the equation then becomes

$$y = \frac{\sqrt{\left[r^2 \times n^2 - a^2 \pm \sqrt{(r^2+n^2-a^2)^2 - 4n^2x(2r-x)}\right] - 4(r-x)^2(r+x)^2}}{2(2r-x)}$$

This equation gives the generating curve, which, rotated on the axis, forms the conoid of equal sections around the quarter ring n, and, of course, the opposite side of the fan calls for a similar conoid. With this section of mouth, and that previously described for the zone of the blades (supposing them to be a logarithmic spiral), and with the supply of air which the velocity of the tips of the blades demands, the air will enter with the least resistance until it reaches the blades, and will fill the fan whilst it is accelerated, and be discharged with the maximum effect.

Next to Combes, Rittinger has most carefully studied the condition

and forces in a fan. He, desiring to obtain the highest velocity of emerging air and the greatest pressure, decided properly that the tips of the blades were the point of maximum effect, and that the fullest advantage could be obtained by the highest velocity. He argued, in antagonism to Combes, that the tips must be radial; and that as the direction of the entering air can only be changed (by means of a cone) into the direction of the radii of the fan, the vanes should have some angle given to them, by which they should admit the air obliquely. Rittinger's section of fan, so far as regards the mouth, approximates to that of which the calculations have been given; but he made the fan, in section through the case at the zone of the blades, relatively much narrower at the extremities of the blades, to meet the condition of the extra velocity he supposed. In fact, the back of the blades of a fan performs nearly as much duty as the front; the inner edges of the back of the blades occupy, at the entering in of the air, the same relative position that the outer edges of the front of the blades do at its exit. At all events, the backs ought to perform just as much duty, and would do so but for the fact that the air is left behind, owing to the velocity of the blades exceeding its inertia and its expansive power, which is the main source of the loss of effect of fans as machines at work. The snap of a whip illustrates how a nearly perfect vacuum is produced by rapidly withdrawing an object in free air. Similarly the radial tips to Rittinger's fans were very inadequately supplied with air behind, and the condition of all radial blades was aggravated by the change of form of the back of the blade.

In a fan, 10 feet in diameter, 2 feet in width at the circumference, and having 62·83 square feet of area of discharge, the openings on both sides should be 7·22 feet in diameter and 3·50 feet in width at the inner edge of the zone of blades. This leaves but 1·39 foot for the width of the zone of blades from the opening to the periphery. Attention is directed to this departure from the usual proportions, to indicate the advantages that would result from a greater number of blades; and the discussion would fail to be understood, unless the opportunity, if not the necessity, of so doing were demonstrated. Air is acted upon by the blades in two ways; first, by the adhesion of the air to the blades, as in the flow of liquids along a surface; secondly, by some shape being given to them, whereby each particle of air is moved in a definite direction, relative to the surface of the blade with which it is in contact, as if it were a ball or a shot.

The French Hydraulic Engineer, M. Darcy, has aptly described the flow of water through a pipe or tube to be a rolling action against the sides; and he has compared it with the slipping of a glove off a finger when the glove is turned inside out by the process.

It is to be borne in mind, that the pressure of air against a surface in relation to its density, at the ordinary barometric and thermometric conditions of head, as compared with that of a column of water representing the same pressure against a similar surface relative to its density, is as 195 to 1; and as the friction or adhesion to the sides of a pipe or tube, or the blade of a rotary fan or centrifugal pump, varies with the pressure, the proportionate friction or adhesion of air to the blades of a fan is much exaggerated for air over water. The coefficient of friction may be less for air than for water, but the resistance, as regards the movement of air and water against surfaces, is much greater for the less dense fluid. It follows, from this adhesion, that the particles of air in contact with the blades have given to them a positive angular velocity, regardless of the shape of the blades tending to produce any other velocity in the direction of the radii. From this reason also it may be explained why, in the instance of a fan with the blades so shaped as to take air in from the periphery towards the centre, the air will, when velocities are given to such a fan sufficiently high to produce a current at all, still pass from the centre outwards, although the quantity may be small. The common magic-lantern exhibitions of rotating figures will give a vivid idea of such a shape for fan-blades, as should induce the air to pass from the periphery to the centre.

The second condition as to the shape of the blades is to move the air as if it were a body without adhesion, and composed of disintegrated shot or spheres, without attraction or friction on each other. Supposing the air reached the inner edge of a radial blade in a fan of the section described, with a full induced velocity, it would be impelled outwards at the angle of 45° with the radius at the inner point of the blade, and would traverse the zone of blades in contact with the blades, in a logarithmic spiral of 45°, and be delivered at the same angle from the radial outer part of the blade, and with the velocity of that part. Were the blade itself, however, to be at an angle of 45° with the radius, the current of entering air would not be diverted, but would pass through the fan in a radial direction, and would escape normal to the periphery, with a velocity of $\sqrt{\frac{1}{2}}$ of that of the tips of the blades. The path of the air across the zone of blades will vary with the angle which the blades present to the radius, and the velocity of discharge will change from that of the tips to zero, as the angle changes from 0° to 90°. But only the surface of the air enclosed between two blades and the sides of the case is in absolute contact with the blades. On the mass of air the blade must have a convected action, so to speak. The passage of the air in the tube, composed of the sides of the fan and the two blades, is strictly an instance where the tube is made to pass away from a fluid more

rapidly than the fluid can follow; and the question of economic result is determined by the relative length of the tube to its diameter.

Where do the sides of the tube act most efficiently on the air, and where is the interior least able to discharge itself against the action of the sides?

If a fan were all blades, or, in other words, if there were an infinite number of them, the action on the air, were it composed of spherical grains, would be perfectly efficient. As it is the friction of the air against the blades is a bar to an excess of number, and the rolling action of the fluid in contact with the blades is yet another influence to be included in the estimation of their proper number and shape.

Practically the arms which carry the blades, or what is to be preferred, a disc separating the two sides of the fan for supporting the blades, and the sides of the case, which may either be attached to and rotate with the blades, or, still better, may be free, exert considerable influence, by the adhesion of the air, on the direction of the currents through the zone of blades. After it has been ascertained that any particular form and number of blades will produce the highest useful effect, at the pressure related to the velocity of the periphery of the fan, if it is desired to have a higher pressure, it will be best obtained by giving a higher velocity to the fan, and not by altering the shape of the blades to a form of less efficiency; unless the desired pressure approaches the strength of the parts of the fan to resist centrifugal force, and it is advisable not to employ a fan of repeated effort, when the blades become beyond question radial, and the useful effect is secondary.

In the years 1856 and 1857, the Author, who was then employed as one of the principal assistants upon the works of the United States Capitol Extension and of the Washington Aqueduct, under the Engineering charge of Captain (now Major-General) M. C. Meigs, had delegated to him, from some prior knowledge of the subject, the investigation of what form of fans should be employed in ventilating the Capitol buildings. A series of experiments with models, based on the reasoning here adduced, gave as the best shape or curvature to the blades, that which has been indicated, a logarithmic spiral of 45°, and showed a loss of mechanical effect when, within the zone of blades, the number of blades employed exceeded that which allowed the heel or inner edge of one blade to much more than lap over the point or outer edge of the next in a radial direction, or in the direction in which the current of air passed, when the maximum discharge was occurring.

The same rule would hold good with fans having radial blades; for as then the direction of the current is at an angle of 45° to the

radius vector, the overlapping of the opposite ends of the two contiguous blades in relation to the current would take place in the same way. Taking a fan of 10 feet in diameter, of the proportions assumed, where the zone of blades has been stated to be 1·65 foot in average width, about sixteen blades would be required for a fan with blades at the angle of 45°, and about twenty-four for the same fan with radial blades. The fan here described is narrow, with large openings on both sides, and numerous blades, as compared with the usual practice; but it possesses the merit of being the smallest in external diameter, of having the largest capacity, and the least surface friction compatible with the contact of the air with the blades.

It is not pretended that a fan of the usual proportions, with the diameter three or four times the width of the opening at the side or mouth, and the relative width much greater than has been assumed, is radically inefficient; nor that in such case, if the number of blades be limited to four, or six, or eight, or where the case is composed of flat plates, there is a total loss of efficiency. So far as the extremities of the blades merely rotate a mass of air which is not passed forward, no power is consumed, upon the principle of the tube closed at the inner end. The air can only be delivered so fast as, by the action of some part of the blade of a fan thus constructed, it can be induced to enter at the restricted openings at the sides. But the rolling of compressed air, intercepted by the outer ends of the blades and the friction upon the enlarged surfaces, must consume more or less power. The real efficiency of such fans is to be measured by the dimensions of a fan of the proportions given, to be inserted or included within them. The following table gives the relative dimensions of sections of fans having a different number of blades, where the diameter of the fan is in each case taken at 10 feet:—

	Diam.	Diameter of Mouths, no newel allowed.	Width of Mouth.	Width of Tips.
	Feet.	Feet.	Feet.	Feet.
For 16 blades 45° logarithmic spiral . . . Or 24 „ 0° „ „ or radial	10	7·42	3 63	2·
12 „ 45° „ „ . . . 18 „ 0° „ „ or radial	10	6·34	3·1	1·35
8 „ 45° „ „ . . . 12 „ 0° „ „ or radial	10	4·88	2·41	0·62

Beyond this last, if not including it, the proportions become impracticable; and in the two last, for small fans, it is better to have the case attached to and revolve with the arms, and to insure proximity of the edges of the blades to the case by the attachment. From numerous experiments on different fans, it is found that the

duty of fans thus proportioned, and adapted to the quantities of air under different pressures, is 65 per cent. of the power applied.

For the fan with logarithmic spiral blades of 45°, the highest velocity of emergence from the periphery is $\sqrt{\frac{1}{2}}$ the velocity of that periphery = 0·707 V, the entire area of the periphery being the area of discharge; but this velocity is not reached for two reasons. First, there are only sixteen points on the entire periphery when the air is subjected to this speed. At usual speeds, about $\frac{8}{10}$ths only of this velocity could be imparted to the current of air, and, upon the principle enunciated, the power at its maximum, if producing 100 per cent. of useful effect, can only be based upon the moving of air through the given opening at $\frac{8}{10}$ths the velocity of the periphery—that is, at 0·5656 V. But only 65 per cent. of the motive power consumed is claimed. This implies the motion of $\frac{8}{10}$ths the quantity, at $\frac{9}{10}$ths the velocity, which, as the resistance varies as the square of the velocity, gives 0·81 for the resistance, and this multiplied by the 0·8 of quantity, equals very nearly 65 per cent. Hence the velocity of discharge of air from such a fan can be safely taken at $0{\cdot}9 \times 0{\cdot}5656 = 0{\cdot}5$, or half that of the periphery. This gives the calculation of quantities and pressure, when the maximum quantity of air the fan can pass is supplied, with no resistance to the influx or efflux beyond the pressure incident to the flowing of air. To pass this air there must be the stated difference of pressure on the two sides of the fan; but the length of duct, or the magnitude of the chamber on either side, is immaterial, frictional resistance being unconsidered. It has been shown, that if the supply or the delivery of air is checked, the quantity passed will be diminished, until none whatever goes through; and the pressure will then be equal to that due to the velocity of the tips of the blades, whatever may be their shape, modified only by the condition, that the air between the blades being not in the same relationship to the blades as that in actual contact with them, there will be a falling off at most perhaps of $\frac{1}{10}$th the pressure. Experiments have shown a falling off of under $\frac{1}{10}$th.

Up to this point it has been possible to demonstrate by reasoning, or with the modification of some coefficients, the proportions enumerated. But there are no accurately determined figures to show, what relationship the quantities of air discharged bear to the increased resistances. The instances in use, although numerous, about one hundred in fact, have been restricted to cases where ducts have been employed, some or all of which have been closed at times; no regularity of working has been adopted; and no experiments have been made to show the variations of pressure when the quantities were increased or diminished. The Author has assumed, in giving the performance of fans, that double the unrestricted pressure could be got

with half the quantity of air. This relationship seems to have been warranted by many results, where the quantity of air has been measured by an anemometer, and the pressure registered by a gauge simultaneously. But the law of the relation of variation of quantity with pressure to this limit, or further limits, has not been determined; the ultimate pressure attainable for the discharge being four times, less 10 per cent., or 3·6 times the pressure of unrestricted discharge.

The assumption, that half the quantity will be delivered under double the pressure, involves the passage of the current of air in a radial direction through the blade at half its unrestricted velocity, and the rotation of the air with the fan at such a rate, that its centrifugal force shall equal the double pressure assumed. It should be borne in mind, that double pressure follows when the air is impelled tangentially at 0·707 the velocity of the tips of the blades, and that this is the speed which would be given to the current outwards, were there an infinite number of frictionless blades, with the logarithmic curve of 45°. That there will yet be discharged quantities of air up to the limit of pressure is certain; but the economic effect of the fan falls off rapidly, as the blades are moved at high velocities through a bath of air without producing proportionate results.

With these estimates of unrestricted discharge and pressure, and the modification of a certain pressure up to double the unrestricted pressure, the limits of fans of proper proportions are brought to definite conclusions.

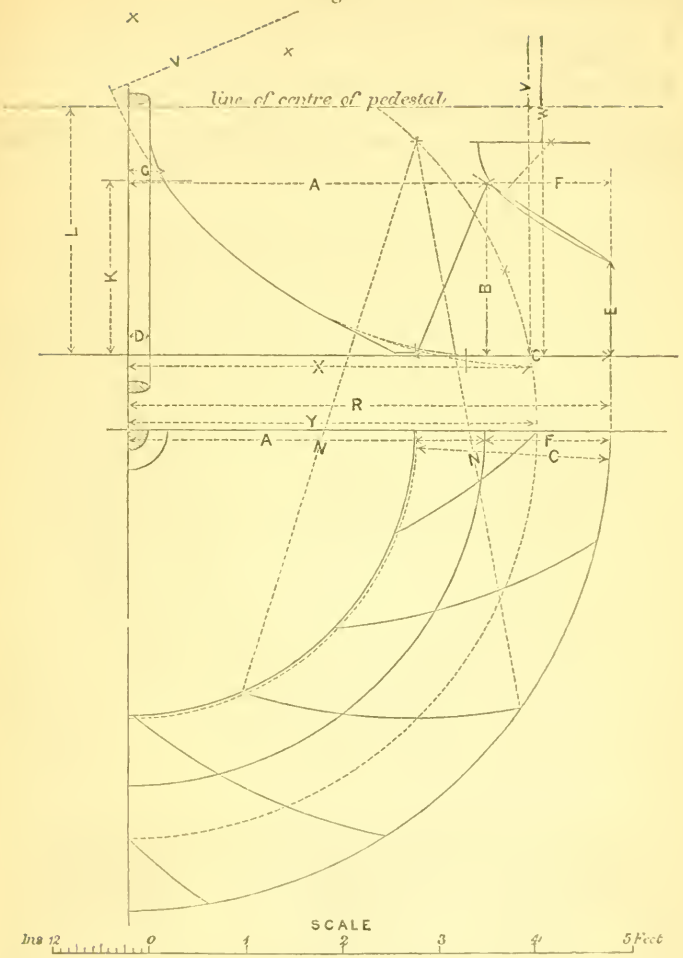
Let there be given any case where a certain quantity of air is to be extracted or delivered per minute. If there is any restricted passage or duct either before or after the fan, it is evident that the area of the periphery of the fan must be less than such restricted passage. The effective velocity of the air must be made by the fan to exceed that of the flow of the air through any openings. Since a fan 10 feet in diameter has an effective opening of 50 square feet, and one 20 feet in diameter has an effective opening of 200 square feet, this limit will reduce the diameters of fans to reasonable sizes. On the other hand, if it be possible to ascertain or assume a pressure to be got by the fan, as the pressure proceeds from the velocity, it follows that the requisite velocity of emergence can easily be calculated, and that the area of the opening at the periphery of the fan can be given for the quantity of air to be moved.

It has been assumed that the fans here described take their air from the chambers freely, and discharge it freely at the extremities. It is possible that trumpet-shaped mouths, or diffusing plates, gradually opening beyond the periphery, will economise some power. Mr. Boyden, in his Fourneyon turbine at Lowell, Mass., found a

gain of 2 per cent. or 3 per cent. from the use of diffusing plates, a gain which, as it was upon and above 90 per cent. of the power applied, was really surprising. But much caution must be exercised in using any appliance to remove air from a fan. The ordinary snail case of blowing fans generally absorbs 10 per cent. or 15 per cent. of the effective duty of such machines, besides making them excessively noisy, although recent constructors have so far removed the case from the fan that it is less objectionable.

Having considered the laws which govern the proportions of fans, it is proposed to examine some of them as constructed. The curved lines given in the preceding description may, without sensible injury to the result, be changed into straight lines where the amount of curvature is small, or into arcs of circles, which, with proper radii and loci for the centres from which the arcs are struck, may be substituted for the more considerable curvature of the contour of the cone, or the logarithmic spiral of the blades.

Fig. 5.



The dimensions in practice then become when R = unity

A =	radius of inlet	= 0·742
B =	width of inner edge of blade	= 0·35
E =	„ outer „ „	= 0·2
C =	„ zone of blades on disc	= 0·4
F =	„ „ „ on case	= 0·258
K =	face of curb in front of disc	= 0·373
L =	place of centre line of pedestal in front of disc	= 0·5+0·08
D =	radius of shaft	= 0·046
G =	„ „ hub	= 0·075
V =	„ „ contour of cone	= 0·94

W = locus for centre of V in front of disc . . . = 0·92
X = „ „ „ „ from centre of fan . . = 0·829
Y = radius of loci of centres for generating curves for blades . . . . . = 1·194
Z = radius of generating curve for blades approximate 45° logarithmic spiral . . . . . = 0·597

Adopting the outline shapes set forth, the following is an example of the general dimensions of a fan 10 feet in diameter:

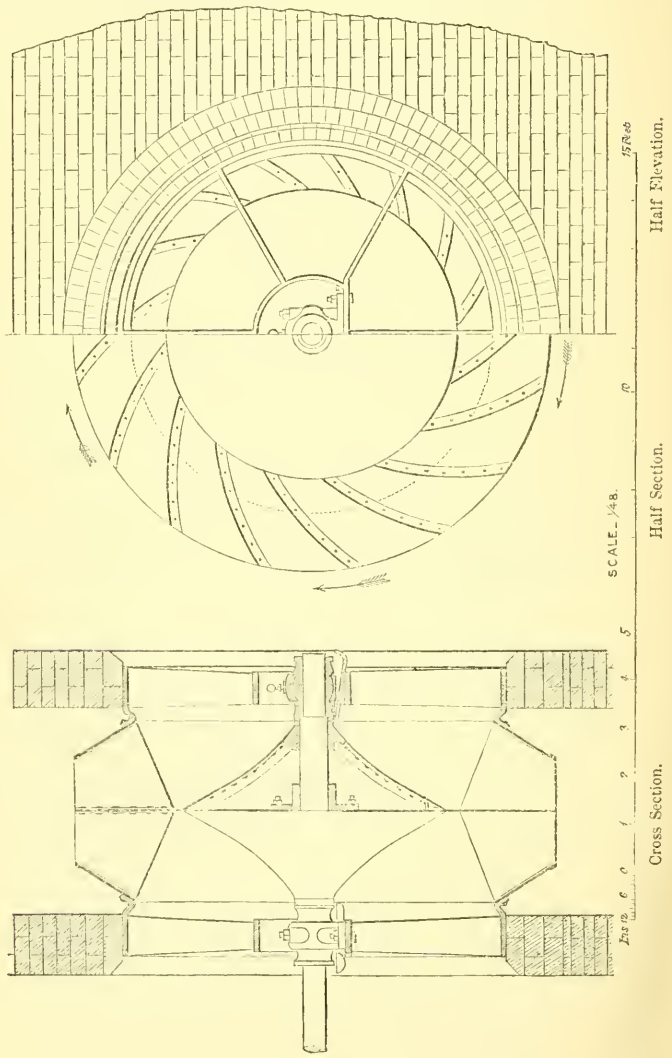


Fig. 6.

The shaft is of wrought iron $5\frac{1}{2}$ inches in diameter between the bearings, and 5 inches in diameter within and beyond them. The length beyond the bearings is at least sufficient for the attachment of the driving pulleys, either upon one or on both sides of the fan, or, which is preferable, is extended to other bearings in the same line with the pulley or pulleys beyond them, so as to carry the belt out of the current of air entering the fan, which is often damp and destructive to belting. Upon this shaft, and in the centre of it, a cast-iron hub with flange is keyed, and to this flange is bolted or rivetted the central disc, which is a plate 10 feet in diameter, and $\frac{3}{8}$ inch thick. Where possible this plate should be a single sheet, but it can be made by two sheets being carefully butted and joined by fish-plates. The disc must be well straightened, and should have the surface where it is joined to the flange faced in a lathe, so that no spring may be given to the plate by bolting or rivetting. The blades are made of No. 10 wire gauge sheet iron, bent to form on a block, and a flange $1\frac{1}{2}$ inch wide should be thrown out for fastening them to the disc. The rivets are about $3\frac{1}{2}$ inches apart, and pass through and hold the two opposite blades at once.

The blades have one or two diagonal braces, from the disc to near the edges of the blades, made of flat half-round iron $1\frac{1}{4}$ inch by $\frac{1}{2}$ inch, and placed on the inside of the curvature, to stiffen the outer projecting edge against any tremulous vibration, and help to resist the centrifugal force upon the blades themselves.

Upon the shaft, at each side of the fan next within the bearings, two hubs are keyed, from which hubs radiate ten light-rib T-castings, 3 inches by 3 inches, and bolted at the outer end to the disc. The umbrella skeleton thus formed has the contour on the top of the T of the cone of the fan, and is covered by No. 18 wire gauge sheet iron, which has been hammered into the shape of the conoidal surface upon a block, the segments of the sheets being rivetted to the T castings, and to the disc of the fan at the base of the conoid. The case of the fan consists first of two castings, one on each side, which resemble cast-iron pulleys, 7 feet 10 inches in external diameter, each with a large ⊐-shaped opening in the centre, to carry the pedestals or bearings, and connected to the rim by six arms, 8 inches broad by $1\frac{1}{4}$ inch thick, placed edgeways to the direction of the entering air. The bearings are 5 inches in diameter and 15 inches in length, the boxes being of cast iron if the speed is not to exceed 150 revolutions per minute, or of brass if it is to exceed that number. Parallel bearings on the shaft are found to be the best for all sizes and speeds, and are much to be preferred to conical ones, which were formerly used, and are still frequently employed. The boxes have ball sockets on them, which rest in corresponding concavities in the pedestals which carry them, and an adjustment of the line of shaft is procured by moving the feet

of the pedestals sideways in the ⊔ opening, or by packing up the pedestal at its bottom.

The pulley-shaped mouth-piece, 7 feet 10 inches external and 7 feet 8½ inches internal diameter, has 9 inches of its face flat, to give a good surface to the brick circle in which it is to be built. The arms join the rim at this flat place.

The rest of the face of the mouth-piece is rounded, so that the opening into the fan is 7 feet 5 inches wide, and a flange 2½ inches wide is provided on the inclination, and around the inside of the fan blades; the entire width of the face of the mouth-piece is 14 inches. The case of the fan consists of two frustra of cones of No. 14-sheet or No. 16-sheet iron, which is rivetted to the flange on the mouth-pieces, and follow the side edge of the blades as closely as possible, the outer edge of these frustra being stiffened by 1¼-inch by ⅜-inch half-round iron.

The mouth-pieces are built into brick walls, 13½ inches thick, the outer 4½ inches of brick wall being splayed at an angle of 45°. The walls form portions of the suction and pressure chambers, of such size and form as the conditions may necessitate. It is advisable that the shaft should project through another wall, separating the suction chamber, or passage, from the belt room.

Fans of less diameter than 8 feet have usually been constructed with cast-iron plate sides in the form of three-fourths of a circular plate, the bottom segment being cut away. For a 6-feet fan this circular plate was 11 feet in diameter. The circle of the opening in the side where the mouth-piece was attached was not concentric with the circle of the side plate, but the mouth-piece was from 5 inches to 1 foot above the centre of the latter. The sides were connected by No. 16 sheet-iron casing round the circular arc of the side plates, while the entire bottom was omitted, to allow connection to the underground flues.

This construction of fan was adapted to the supply of air for puddling and heating furnaces, which in the United States have nearly always a forced blast, with considerable economy of fuel for a result.

The fan most frequently used in the United States for the ventilation of public buildings, and that which was first used at the United States Capitol Extension, by Gen. M. C. Meigs, Engineer in charge of the work, is of the form described, except that only one side of the fan is employed. The disc is made from wooden radial boards, and the fan is placed in contact with a circular opening in the walls of the building, which opening is built in masonry to the shape of the side edges of the blades. The air enters in freely from one side of the wall, and is delivered into a large room or chamber on the other, from which the ducts to convey the air over the building radiate.

A fan 10 feet in diameter, having an absolute area of discharge

of 62·8 square feet, and an effective area of discharge of 50 square feet, as first described, approximates nearly to the following results:

TABLE I.

No. of Revolutions per minute.	Maximum quantity of Air per Minute.	Pressure for this quantity. Power in Water Column.	Pulley and Belt required. Diameter of Pulley; Width of Pulley.	Horse-Power.
	Cubic Feet.	Inch.	Ft. In. In.	
100	80,000	0·153	3 0 × 6	3
150	120,000	0·344	3 6 × 10	10
200	160,000	0·613	5 0 × 12	23
250	195,000	0·957	2 pulleys. 4 4 × 10	44½
300	235,000	1·38	2 pulleys. 5 3 × 12	77
350	275,000	1·88	2 pulleys. 6 3 × 14	122

A fan of the same dimensions, discharging under double the pressure given above, may be assumed to give but half the volume of air, as follows:

TABLE II.

No. of Revolutions per Minute.	Quantity of Air delivered per Minute.	Pressure in Water Column.	Dimensions of Pulleys.	Horse-Power.
	Cubic Feet.	Inches.	Diameter. Ft. In. Width. In.	
100	40,000	0·305	3 0 × 6	3
150	60,000	0·685	3 6 × 10	10
200	80,000	1·23	5 0 × 12	23
250	97,500	1·91	2 pulleys. 4 4 × 10	44½
300	117,500	2·76	2 pulleys. 5 3 × 12	77
350	137,500	3·76	2 pulleys. 6 3 × 14	122

The dimensions of the pulleys are obtained from the investigations instituted by the Author, in which he was assisted by Mr. H. R. Town, in 1867, and are based upon such assumed relationship between the diameters of the pulley on the fan and of the pulley transmitting the power to it, and such distance between the pulleys, as will give a contact of the belt of 150° on the fan pulley

at least, where a belt of 1 inch in width will impart to a pulley 1 foot in diameter a fan of 140·2 lbs. each revolution. Taking this as a maximum duty of a belt, it has been further assumed that, by doubling the dimensions and adding an arbitrary constant of five times the diameter of the fans in feet, ample belt power to meet the contingencies of damp or dry belts and of centrifugal force on the belt, will have been provided for.

The experiments referred to were published in the Journal of the Franklin Institute of the State of Pennsylvania for January, 1867.

TABLE III.—FANS to be used in the VENTILATION of BUILDINGS or MINES.

Diameter of Fans.	Revolutions per Minute.	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure.*	Pressure, difference between inlet and outlet of Fan corresponding to Number of Revolutions taken.*	Horse Power required to deliver the Quantity of Air at given Pressure.	Dimensions of Pulleys **			Proper Sectional Area of Delivery Air Duct, or Passage.***
					Number of Pulleys.	Diameter of Pulleys.	Width of Belt demanded.	
Ft.	Number.	Cubic Feet.	Water Column In. dec.	H.P.	No.	Ft. In.	Ft. In.	Square Ft. dec.
16	$62\frac{1}{2}$ to 125	102,500 to 205,000	0·31 to 1·23	$7\frac{1}{2}$ to 59	2	8 4	1 3	160·8
14	70 ,, 140	80,000 ,, 160,000	,, ,, ,,	$5\frac{3}{4}$,, 46	2	7 6	0 10	113·2
12	83 ,, 167	57,500 ,, 115,000	,, ,, ,,	$4\frac{1}{3}$,, 33	2	6 9	0 8	90·5
10	100 ,, 200	40,000 ,, 80,000	,, ,, ,,	$2\frac{7}{8}$,, 23	2	5 2	0 6	62·8
8	125 ,, 250	25,500 ,, 51,000	,, ,, ,,	$1\frac{7}{8}$,, $14\frac{3}{4}$	1	4 0	0 8	40·2
7	140 ,, 280	20,000 ,, 40,000	,, ,, ,,	$1\frac{1}{2}$,, $11\frac{1}{2}$	1	3 6	0 6	28·3
6	167 ,, 333	14,400 ,, 28,800	,, ,, ,,	1 ,, $8\frac{1}{4}$	1	2 8	0 5	22·6
5	200 ,, 400	10,000 ,, 20,000	,, ,, ,,	$\frac{3}{4}$,, $5\frac{3}{4}$	1	1 10	0 5	15·7
4	250 ,, 500	6,400 ,, 12,800	,, ,, ,,	$\frac{1}{2}$,, $3\frac{3}{4}$	1	1 4	0 4	10·05

* Double the quantity of air will be delivered each minute if the resistance to discharge or suction is brought down to one-half the pressure given in the pressure column, and the pressures may be increased (the number of revolutions of the fans remaining constant), by closing partly the inlet or outlet, the quantity of air delivered being gradually diminished until the inlet or outlet be entirely shut off, when the pressures will have risen to double those stated in the table.

** The dimensions of pulleys and belt refer to the largest capacity of the fans given in the Table, it being supposed that it may be desirable to range from the lowest quantity and pressure to the highest in each case.

*** The sectional area of the inlet or suction air-duct or passage should exceed the areas given by 1·4 time, to allow a fan to produce its fullest effect. It has been found, when it was inconvenient to make the air-ducts or channels of full sectional area to the end of a system of distribution, by enlarging them 0·025 per foot of length, so that outlets and channels, at the distance of 400 feet, were provided with double sectional areas, that the falling off of pressure was satisfactorily compensated for at the more distant outlet. It is obvious this rule will not apply to very small air-passages. When the relationship of quantity and pressure corresponds to that given in the table, and it is never expected that a larger quantity will be required at a reduced pressure, the sectional area of the delivery air duct may be reduced one-half, or nearly to that extent. The sectional area given admits the passage of double the quantity of air at one-half the pressure. The frictional resistances of the sides of a duct are so considerable, that the largest duct possible should always be used, even when somewhat in excess of the dimensions given as to be desired.

TABLE IV.—FANS to be used for the SUPPLY of AIR under the GRATES of PUDDLING or HEATING FURNACES.

Diameter of Fans.	Revolutions per Minute.	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure.*	Pressure, difference between inlet and outlet of Fan, corresponding to Number of Revolutions taken.*	Horse Power required to deliver the Quantity of Air at given Pressure.	Dimensions of Pulleys.**			Proper Sectional Area of Delivery Air Duct, or Passage.***
					Number of Pulleys.	Diameter of Pulleys.	Width of Belt demanded.	
Ft. In.	Number.	Cubic Feet.	Water Column In dec.	H.P.	No.	Ft. In.	In.	Square Ft. dec.
7 0	280 to 420	40,000 to 58,750	1·23 to 2·76	$11\frac{1}{2}$ to 39	2	3 0	8	28·3
6 0	333 ,, 500	28,800 ,, 42,300	,, ,, ,,	$8\frac{1}{4}$,, 28	2	2 0	8	22·6
5 0	400 ,, 600	20,000 ,, 29,400	,, ,, ,,	$5\frac{3}{4}$,, $19\frac{1}{2}$	2	1 8	5	15·7
4 0	500 ,, 750	12,800 ,, 18,800	,, ,, ,,	$3\frac{3}{4}$,, $12\frac{1}{2}$	1	1 2	8	10·05
3 6	560 ,, 850	10,000 ,, 14,700	,, ,, ,,	$2\frac{7}{8}$,, $9\frac{3}{4}$	1	1 0	7	7·07
3 0	667 ,, 1,000	7,200 ,, 10,600	,, ,, ,,	2 ,, 7	1	0 10	$5\frac{1}{2}$	5·65
2 6	800 ,, 1,200	5,000 ,, 7,350	,, ,, ,,	$1\frac{1}{2}$,, $4\frac{7}{8}$	1	0 8	$4\frac{1}{2}$	3·92
2 0	1,000 ,, 1,500	3,200 ,, 4,700	,, ,, ,,	$\frac{9}{10}$,, $3\frac{1}{8}$	1	0 6	$3\frac{1}{2}$	2·51

TABLE V.—FANS to be used for the SUPPLY of AIR to TUYERES, as CUPOLAS, SMITH'S FORGES, HOLLOW FURNACES, &c.

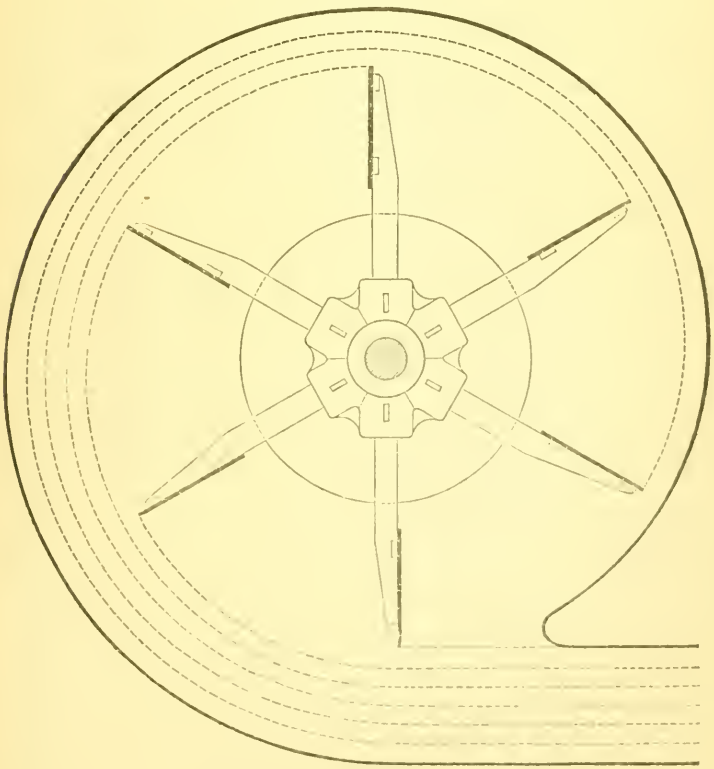
Diameter of Fans.	Revolutions per Minute.	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure.*	Pressure, difference between inlet and outlet of Fan, corresponding to Number of Revolutions taken.*	Horse Power required to deliver the Quantity of Air at given Pressure.	Dimensions of Pulleys.**			Proper Sectional Area of Delivery Air Duct, or Passage.***
					Number of Pulleys.	Diameter of Pulleys.	Width of Belt demanded.	
Ft. In.	Number.	Cubic Feet.	Water Column In. dec.	H.P.	No.	Ft. In.	In.	Square Ft. dec.
3 6	850 to 1,000	14,700 to 16,900	2·76 to 3·75	$9\frac{3}{4}$ to $15\frac{1}{2}$	1	1 2	8	7·07
3 0	1,000 ,, 1,167	10,600 ,, 12,200	,, ,, ,,	7 ,, $11\frac{1}{4}$	1	0 10	7	5·65
2 6	1,200 ,, 1,600	7,350 ,, 9,800	2·76 ,, 4·93	$4\frac{7}{8}$,, $11\frac{1}{2}$	1	0 8	7	3·92
2 0	1,500 ,, 2,000	4,700 ,, 6,200	,, ,, ,,	$3\frac{1}{8}$,, 8	1	0 6	6	2·51
1 6	2,000 ,, 2,667	2,600 ,, 3,500	,, ,, ,,	$2\frac{1}{2}$,, $4\frac{1}{4}$	1	0 $4\frac{1}{2}$	4	1·41

*, **, *** The asterisks refer to the notes to Table III.

Mr. R. Briggs said he had made a full and thorough investigation of the subject twelve years ago, and this he had endeavoured to lay before the Institution, in such a manner that the data then obtained might be utilized, for the purposes of the ventilation of mines or of buildings, or in any other cases where fans were required for impelling air.

Mr. E. A. Cowper directed attention to a table (p. 298) showing the results of a large number of experiments he had made, in the year 1850, on the useful effect that could be obtained from rotary fans. He observed that the plan of making spiral cases for fans was an old and well-known one, and he believed it was correct in principle. He had during the last few years seen fans with concentric cases, and a throat or delivery on one side only; also designs for fans with no case at all, but opening all round into a large box or space, from which a throat or delivery-pipe was intended to be led for the delivery of blast. But he thought that if it was required to deliver

Fig. 7.



Fan for Foundry and other like purposes.

TABLE VII.—Useful effect obtained

Number of Experiment.	Date of Experiment.	Number, and Size of Blades in Inches.	Revolutions of Engines per Minute.	Revolutions of Fan per Minute.	Velocity of Tips of Blades, in Feet per Min.	Theoretical Velocity of the Air, in Feet per Minute.	Pressure of the Blast, in Inches of Water.
	1850.						
19	Aug. 10, 1 P.M.	16 × 12	20	514·28	8818·9	7,740	4
		4 blades	22½	578·57	9921·26	8,646	5
		.. ..	25	643·3	11031·24	10,590	7½
18	Aug. 9, 5·30 P.M.	.. ..	20	514·28	8886·22	7,974	4¼
		16 × 13¼. . . .	22½	578·57	9996 99	8,646	5
		4 blades	25	643·3	11115·49	10,590	7½
15	Aug. 11 . . .	.. ..	..	..	..	..	..
		.. ..	..	..	..	..	..
		4 blades	25	643·3	11115·45	10,938	8
36	Nov. 29 . . .	6 blades 16 × 8 .	..	712·5	12312·0	9,670	6¼
		Centre plate . . .	..	..	..	11,280	8½
37	Ditto	.. ..	..	..	..	9,670	6¼
		.. ..	..	..	..	11,280	8½
20	Aug. 11 . . .	18¼ × 12. . . .	20	514·28	8078·38	7,237	3½
		4 blades	22½	578·57	9088·11	8,646	5
		.. ..	25	643·3	10104 95	9,858	6½
22	.. ..	18¼ × 18 × 13¼. .	20	514·28	8886·22	8,202	4⅔
		4 blades	22½	578·57	9996·99	9,072	5½
		.. ..	25	643·3	11115·45	10,590	7½
32	Nov. 16 . . .	6 blades 16×8, with	..	712·5	12312·0	9,954	6⅝
		Centre plate. . .	..	..	..	11,358	8⅝
35	Nov. 29 . . .	.. ..	..	..	..	..	..
		.. ..	..	..	..	..	..
21	Aug. 11 . . .	18¼ × 12. . . .	20	514·28	7270·44	6,696	3
		4 blades	22½	578·57	8179·14	8,202	4½
		.. ..	25	643·3	9094·33	9,474	6
34	Nov. 17 . . .	6 blades 16 × 8, with	..	712·5	12312·0	9,670	6¼
		Centre plate. . .	..	..	..	11,280	8½
16	Aug. 9, 5 A.M.	18¼ × 13¼ . . .	20	514·28	8886·22	8,646	5
		4 blades	22½	578·57	9996·99	9,474	6
		.. ..	25	643·3	11115·45	10,938	8
38	Nov. 18, 1 P.M.	6 blades	..	712 5	12312·0	9,474	6
		16 × 8 centre plate .	..	..	..	11,280	8½
40	Ditto, 5·30 P.M.	And guides . . .	..	..	..	9,474	6
		.. ..	..	..	..	11,280	8½
33	Nov. 17 . . .	.. ..	..	..	..	9,670	6¼
	„ 3 . . .	.. ..	..	..	..	11,280	8½
30	Nov. 2 . . .	6 blades	..	..	..	9,858	6½
		16 × 8	..	..	..	11,280	8½
31	Nov. 3 . . .	.. ..	..	..	..	9,858	6½
		.. ..	..	..	..	11,280	8½
39	Nov. 18, 4·30 P.M.	6 blades 16 × 8 . .	..	..	..	9,474	6
		Centre plate . . .	..	..	..	11,280	8½
28	Nov. 15, 1 P.M.	And guides 16 × 8 .	..	..	..	9,474	6
		4 blades	..	..	..	10,938	8

from ROTARY FANS.

Pressure of the Blast, in Ounces per Square Inch.	Diameter of Fan Tips of the Blades.	Area of One Blade, in Square Inches.	Area of Discharge, in Square Inches.	Area of Water Gauge, in Square Inches.	Total Power of Engines. I.H.P.	Friction of engines and shop shafting I.H.P.	Power absorbed by Fan and Counter Shaft. I.H.P.	Weight and Velocity of Air delivered. I.H.P.	Useful Effect. I.H.P.
	Ft. In.								
2·308	5 5½	192·0	194	28·27	40·949	22·385	18·584	6·9	37·17
2·885	..	..	..	..	48·108	25·662	22·786	9·63	42·26
4·3275	..	..	..	..	60·8	28·43	32 37	17·7	54·68
2·452	5 6	212 0	211	..	43·758	23·4	20 358	7·81	38·31
2·885	..	..	..	..	50 542	25·7	24·84	9·46	40 09
4·3275	..	..	..	..	71 82	31·2	40·62	18·3	45·0
..	..	..	..	..	57·662	26·325	31·337	16·39	52·3
..	..	..	..	..	45·084	21·103	20·981	13·7	65·3
1·616	..	..	..	..	74·263	30 859	43·404	27·73	63·88
3·606	..	128·0	354	..	68·88	23·31	45·51	23·37	52·4
4·904	..	..	128	..	49·18	..	25·84	13·4	51·8
3·606	..	..	351	..	68·44	24·47	13·97	23 37	51·3
1·904	..	..	128	..	57·18	..	32·71	13·4	41·0
2·0195	5 0	227·25	220	..	32·823	21·411	11·412	6 088	53·27
2·885	..	..	..	..	41·915	24·569	17·346	10·33	59·5
3·7505	..	..	..	..	56·897	27·727	23·17	15·1	66·46
2·5965	5 6	291·3	351	..	50·594	24·103	26·491	14·28	53·88
3·1735	..	..	..	..	62·858	26·325	36·533	19·3	52·8
4·3275	..	..	..	..	80 14	30·859	49·181	31 45	63·9
3·822	..	128·0	..	..	71 48	26·7	17·7	25·8	54·0
4·976	..	..	128	..	64·31	..	37·6	13 6	36·1
..	..	..	354	..	68·0	24 813	..	23·37	54·1
..	..	..	128	..	55·91	..	31·1	13·4	43·1
1·731	4 6	..	220	..	30·277	21·111	8·867	4·82	54·3
2·5965	..	..	..	..	37·949	24·569	13·38	8·87	66·2
3·462	..	..	..	..	51·138	27·727	23·411	13·66	58·2
3·606	5 6	128·0	351	..	67·19	26·1	41·09	23·37	56·8
4·904	..	..	128	..	55·0	..	28·9	13·4	46 3
2·885	..	241·81	240	..	42·43	22·815	19·62	11·33	57·74
3·462	..	..	..	..	55·662	25 754	29·908	14 9	49·82
4·616	..	..	..	..	71·634	30·956	40 678	22·94	56·39
3·462	..	128·0	354	..	65·78	28·32	37·46	22·2	58·7
4 904	..	..	128	..	59·88	..	31·56	13 4	42·4
3·462	..	..	354	..	62 32	25·34	36·98	22·0	59·4
4·904	..	..	128	..	58·65	..	33·31	13·4	40·2
3·606	..	..	354	..	66·07	27·34	38·73	23·37	60·3
4·904	..	..	128	..	58·95	..	31·61	13·4	42·4
3·7505	..	..	354	..	69·42	28·88	40·57	24·8	61·1
4·904	..	..	128	..	50·63	..	21·78	13·4	61 5
3·7505	..	..	354	..	69 73	27·63	40·1	34·8	61·8
1·904	..	..	128	..	48·88	..	21·25	13·4	63·0
3·462	..	..	354	..	60·87	25·34	35·53	22·0	61·9
4·904	..	..	128	..	57·97	..	32 63	13·4	41·0
3·462	..	..	354	..	62·05	29·27	32·78	22·0	67·1
4·616	..	..	128	..	55·81	..	26·57	12·23	46·0

TABLE VII.—Useful effect obtained

Number of Experiment.	Date of Experiment.	Number, and Size of Blades in Inches.	Revolutions of Engines per Minute.	Revolutions of Fan per Minute.	Velocity of Tips of Blades, in Feet per Min.	Theoretical Velocity of the Air, in Feet per Minute.	Pressure of the Blast, in Inches of Water.
	1850.						
29	Nov. 15, 1 P.M.	.. ..	..	..	..	9,678	$6\frac{1}{4}$
		.. ..	..	..	..	10,938	8
23	Aug. 23	$18\frac{1}{4} \times 12$. . . .	..	..	11191·95	10,234	7
	„ 26	4 blades	..	..	..	10,928	8
		.. ..	..	..	..	9,858	$6\frac{1}{2}$
17	Aug. 10, 7·30 P.M.	$18\frac{1}{4} \times 12$. . . .	20	514·28	8549·62	8,202	$4\frac{1}{2}$
		4 blades	$22\frac{1}{2}$	578·57	9618·32	9,474	6
		.. ..	25	643·3	10695·22	10,590	$7\frac{1}{2}$
27	Sept. 11	$18\frac{1}{4} \times 10$. . . .	..	712·5	11191·95	9,474	6
		4 ditto	..	..	..	10,500	$7\frac{3}{8}$
25	Sept. 4	16×12	..	..	..	9,376	$5\frac{7}{8}$
		4 ditto	..	..	..	10,234	7
24	Sept. 4	17×12	..	..	..	9,474	6
		4 blades	..	..	..	10,234	7
26	Sept. 8	16×11	..	..	..	9,173	$5\frac{7}{8}$
		4 blades	..	..	..	10,140	$6\frac{7}{8}$

air at a given pressure and velocity, and that this velocity had once been imparted to the air, it would be true economy to let the air retain its velocity in passing a short distance round a smooth case, and thence out at the delivery-pipe; and that, on the contrary, it would be objectionable to allow the air to pass into a large space, thus losing its velocity and momentum, and wasting power by eddies and waves directed only against the air already in that space, and against the sides of the box. In fans that had concentric cases, with an aperture only on one side, the irregular motion of the air through the fan must militate much against a good result, as the air could only get into the fan with a jump or sudden motion, on the side where some air was escaping from the fan; and then it must remain in the fan and be carried round by the blades, until it came in its turn to the aperture, when it could escape, and so allow room for more air to enter behind it, in the centre of the fan. In such a fan the only blades that delivered air were those that were, for the moment, opposite the aperture; whilst the others were simply carrying the air between them round the case, thus causing needless friction. In a fan with a case in the form of an arithmetical spiral, on the contrary, every blade was at all times working usefully and equally, so that a number of laminæ of air were delivered, one from each blade, and these maintaining their velocity, joined in forming a single current of air, which passed out at the delivery-pipe with the full force and velocity that had been given

from ROTARY FANS.

Pressure of the Blast, in Ounces per Square Inch.	Diameter of Fan Tips of the Blades.	Area of One Blade, in Square Inches.	Area of Discharge, in Square Inches.	Area of Water Gauge, in Square Inches.	Total Power of Engines, I.H.P.	Friction of engines and shop shafting, I.H.P.	Power absorbed by Fan and Counter Shaft, I.H.P.	Weight and Velocity of Air delivered, I.H.P.	Useful Effect, I.H.P.
	Ft. In.								
3·606	5 6	..	354	..	63·5	28 7	34·8	23·37	67·1
4 616	..	..	128	..	51·6	..	22·9	12·23	53·4
4·039	5 0	219·0	220	..	51·2475	25·963	25·284	17·22	68·0
4·616	..	..	157	..	47·484	..	27·521	15·0	70·1
3·7505	..	..	354	..	55·8187	22·083	33·735	24·78	73·4
2·5965	5 3½	..	220	..	35·126	20·553	14·573	8·87	68·6
3·462	..	..	..	..	45·249	24·613	20·636	13 66	66·1
4·3275	..	..	..	..	58·272	27·397	30·875	19·09	61·8
3·462	5 0	182·5	354	..	58·2	27·59	30·7	21·99	71·6
4 255	..	..	182	..	51·79	..	24·2	15·25	63·0
3·898	..	192·0	354	..	56·094	27·33	28·764	21·31	74·09
4·039	..	..	194	..	51·23	..	23·9	15·18	63·5
3·462	..	201·0	..	..	56·84	27·69	29·1	21·9	74·2
4·039	..	..	204	..	50·94	..	23·25	15·97	68·68
3·245	..	176 0	354	..	54·75	28·34	26·41	19·97	75·16
3·967	..	..	180	..	49·82	..	24·48	13·7	63·8

to it, deducting a little for friction; thus the air entered the fan, and gradually attained its full velocity, as the distance from the centre increased; with a steady and regular motion; and more air was delivered from a given sized fan, than if the casing was of a form that did not allow of a regular and constant delivery. In the case of fans, for ventilating coal pits and mines, this was an important consideration; and he trusted that fans would be used more and more for such purposes, as they were well adapted for the work, and on an emergency, such as a sudden outburst of gas, or a 'blower,' the ventilation could be largely augmented by increasing the speed of the fan; whereby the risk of open furnaces at the bottom of the shaft—a source of great danger in fiery pits—would be avoided.

Fig. 7 (p. 297) was an outline for a well-proportioned ordinary fan for foundry and such like purposes. The hole in the centre might be one-half the diameter of the blades, and the width one and a-half times the radius of the hole, the arithmetical spiral being one that opened in one turn the depth of the throat or delivery-pipe, and the number of blades being four to six for all ordinary sized fans.

Table VII. showed that, to obtain a high economical result, a large area of opening was required, or in other words, that a fan when working to the best advantage would throw a very large quantity of air. In the best designs he had obtained upwards of

75 per cent. of useful effect, the power of the air being calculated by its pressure and velocity, and the power applied being taken very carefully on the average of three indicator figures for the full power, and three for the friction of the engines, which was subtracted from the full power, to get the net power employed.

He might state that a fan of 10 feet in diameter could deliver 88,000 cubic feet of air per minute under a pressure of 6 inches of water; and one of 15 feet in diameter could deliver 199,000 cubic feet of air under the same pressure of water, for mining purposes.

Mr. Hawksley, Vice-President, said, in his opinion the effect of a fan was independent of the magnitude of the case in which it was inclosed; excepting only that the case might be contracted so as materially to interfere by its friction with the motion of the air. He thought it could be proved by practice that if there was a fan in a case as large as the meeting room of the Institution, the effect of the fan would be all the more powerful. In fact, he believed the pressure, as given by the velocity of the fan, was independent both of the size and shape of the case, provided the case was so large as not to impose any considerable resistance to the motion of the air; and that the larger the case was the better. There were several applications—very useful and successful ones—of rotary motion communicated to air by means of fans working in the open atmosphere; but in these cases they were not blowing fans but exhausting fans. That was only estimating the action of the fan in the reverse way—putting exhaustion for pressure. The one, after all, was but the mechanical analogue of the other; and if the apparatus were rightly made, and properly proportioned, the amount of exhaustion in the one case would be exactly equal to the amount of pressure in the other case. Nor did he think that it was material, either with regard to fans which put air in motion, or with regard to fans which put water in motion, what might be the figure or description of the fan. It was immaterial whether the fan was straight-armed or inclined, inasmuch as the effect depended entirely upon centrifugal motion, and centrifugal motion was really and truly independent of the figure of the fan. A valuable instrument formerly used in water-works, as a means of communicating power—the Barker's wheel—was one of the best turbines, if not the best, ever invented; and all these peculiar forces and admirable mechanical contrivances, which were expended in the case of the turbine, resulted in no better derivation of mechanical power than that which was given by a properly constructed Barker's wheel. He was decidedly of opinion that it was immaterial what was the form of the arms of the fan, provided there was no undue resistance or suction of the air at the centre of the fan; and he thought any kind of case would do if it was only large enough. The real effect was produced by the amount of the centrifugal

force, and by no other force whatever; consequently the figure of the fan had very little to do with the question, because the amount of centrifugal force, derived from a circular motion, was much the same whatever the figure of the fan might be. The curvilinear fans, along the surface of which it was supposed air, water, or gas ran very easily till they got to the outside, really produced little or no additional effect; because, so enormous was the velocity of the fan, with regard to amount of air trending back, that really it worked out at last to be a straight arm in practice.

Mr. BRAMWELL observed, in reference to the remarks as to the form of the fan case being immaterial provided it was large enough, that that was a most essential qualification; but it occurred to him that "large enough" must have different meanings, because the same dimensions which would be large enough with a circular case would not be large enough to get the best effect out of the fan if the case were made square. Then, again, it was further said, that for purposes of exhaustion a fan would act perfectly well in the open air without any case (except, of course, the inlet conduits); but it should be borne in mind, that when a fan was used for the purpose of exhaustion, say, in the ventilation of a colliery, where the object was to obtain exhaustion and not a blowing pressure, if the motion given to the outgoing air could be utilized to increase the exhaustion a desirable end would be obtained. If a fan worked in an inclosed case of proper shape, and if the outlet of the case was of the form of a diverging tube, he believed it had been established by experiment, as well as laid down in theory, that the result was to convert the momentum of the outgoing air into a power producing exhaustion. A result such as this could not be obtained if the fan were to work without any case at all. He thought that the experiments on different centrifugal pumps and upon turbines did not bear out the view that the form of the blades was unimportant. He quite agreed that if the object were merely to ascertain what was the ultimate head to which water could be kept raised by a centrifugal pump without any delivery of the water, or, what was the same thing, the maximum pressure of air that could be produced by any blowing fan when the outlets of that fan were closed, then the form of blade was not important; but he thought experiment had clearly demonstrated that, so soon as either a centrifugal pump or a blowing fan was put to do the required useful work of quantity delivered multiplied into height raised or inches of pressure sustained, then the form of blade became of the very highest importance. Twenty years ago experiments were made to ascertain the effects produced by working fans tandem fashion, that was by placing one fan so as to deliver into the inlet of another. The result was that if the pressure of the first fan was 1, the pressure

of the second fan was nearly 2; and on carrying out the arrangement still further, the pressure of the third fan became nearly 3. It appeared to him that this was one of the best arrangements that could be used, where considerable pressures were required.

Mr. G. C. Greenwell said that in a colliery two fans were employed to exhaust the air; but it was found that these two fans only did more work than a single one when the second one was made to act upon the air discharged by the first. With regard to ventilation he believed that, as applied to mines, the subject was of more interest than in any other point of view. In experiments which had been made, it was found that the friction of water passing through pipes was much the same whatever the material of the pipe; but when air went through pipes of different internal surfaces, it was found that the coefficients of friction were different, as shown by Messrs. Girard, D'Aubuisson, and others: and experiments were needed to show what the coefficient of friction really was with regard to mines.

Mr. Hawksley, Vice-President, remarked that the laws of friction found to belong to the flow of air in mines agreed almost perfectly with the results of observations on the flow of air in pipes; but in mines the whole system was generally of a very complicated character. In many cases the area of the air-ways could be found approximately; but in other cases the area of the air-ways changed very rapidly in the course of a few yards, and when that was multiplied over a considerable number of miles, as sometimes happened to be the case, the problem became one of a very unsatisfactory character, not because information on the subject was defective, but because circumstances did not allow the application of that knowledge to the particular cases in question in a satisfactory manner. Then there came another difficulty, from the large amount of 'trapping' which went on in coal mines, which 'trapping' was always more or less imperfect; and the consequence was a great amount of leakage, which, again, materially affected the question. However, twenty years ago he had made an investigation of the character which had been mentioned for the late Mr. Nicholas Wood, who was enabled, in several of the large collieries under his control in the north of England, to carry out some admirable and careful experiments, and the results of those experiments exactly conformed with the formulæ. At the same time it was rare indeed that such experiments could be made, for generally the circumstances were so complicated, that it was almost impossible to get a clear and satisfactory passage for the air through ways of one diameter into which leakage from other passages occurred. Nevertheless those experiments turned out so satisfactory, that he had no hesitation in saying there was little if anything to learn with regard to the magnitude of the coefficient

of friction which was applicable to the case of air in motion. The same remark applied to gas and to water. Experimenters not well acquainted with the difficulties of the subject, sometimes got extremely discordant results, and these were attributed to defects in the scientific principles, whereas it had not been possible to apply those principles with exactitude. He would give an instance with regard to water-pipes. Friction was frequently found to arise in what might be deemed a most unaccountable manner. On investigation it was found to be due mainly to oxidation. It often happened that, in a long water-pipe, the internal diameter of the pipe, along which the water travelled, had diminished by one half, simply by the nodular concretions from oxidation, which formed on the sides of the pipe. Experiments made upon pipes so clogged always gave indications of an amount of friction, which were deemed to be, till the conditions had been investigated, perfectly abnormal. When those conditions were known, there was very little discrepancy between one experiment and another. That applied as much to the motion of bodies through water, as to any other cases of friction. All the formulæ followed the same law though their several magnitudes were very different.

Sir Charles Fox observed that nearly forty years ago Captain Ericsson expressed his opinion that the best arrangement for a fan was between two parallel walls instead of in a case. Fans were generally placed in a case because a direct current of air was required in a particular direction. He further expressed his belief that the most approved fan was the ordinary one with straight arms.

Mr. W. C. Unwin agreed to a great extent with Mr. Hawksley, that the form of the vanes of the fan had but little influence on the head or pressure. Whatever the form of the blade, whether radial or curved, nearly the same pressure was produced in the case, at least so long as the volume of flow was not very great. But in regard to the efficiency of the fan, or the ratio of the work expended in driving it to the useful work in the air pumped, the form of the vanes had a very considerable influence.

There were two great sources of loss in a fan or centrifugal pump with straight radial vanes. In a centrifugal pump or turbine the condition of maximum efficiency was, that the water should enter and pass through the wheel without any sudden change of velocity. With any sudden change of velocity, which was called a shock, there was a waste of mechanical energy by its conversion into heat. Now in the centrifugal fan or pump, with straight radial blades, there was a sudden change of velocity at the moment the fluid entered within the inner circle of the revolving blades, and another when it passed their outer tips. The air entering the central orifice flowed towards the vanes, radially, with

a velocity dependent on the volume of flow. The moment the fluid entered the circle of the revolving arms, there was impressed on it a tangential velocity equal to that of the inner ends of the revolving blades, and in the sudden increase of velocity energy was wasted. In order to pass the air into the revolving wheel without wasting energy, the inner ends of the blades must be inclined to the radius at an angle whose tangent was in the direction of the motion of the fluid relatively to the blades. That condition fixed absolutely, for any given quantity of air to be pumped, the proper angle of the inner ends of the blades. So also at the outer ends of the blades, if the fan disc were placed in a contracted case, the moment the particles of air left the outer ends of radial vanes with a great tangential velocity equal to that of the blade tips, they entered into a mass of air flowing out of the case with a comparatively low velocity. Hence there was shock and loss of energy. Mr. Appold reduced the loss at the tips of the blades by recurving them, so as to give the fluid a backward flow relatively to the blades. That reduced the absolute velocity with which the air left the fan, and consequently the waste of energy in passing from the fan or pump disc to the casing.

There was, however, another way in which the energy of motion in the air leaving the fan disc might be utilized without shock; viz., when the fan was surrounded by a large case, or revolved between parallel walls. Then round the fan disc there was formed a mass of revolving fluid, termed by Professor Rankine a free vortex, obeying well-known laws first discovered by Professor Thomson. The advantage of permitting such a revolving mass was, that the head at its circumference was the centrifugal head due to the revolving mass of air in the fan disc plus the centrifugal head due to the revolving mass outside the disc, and the latter part of the pressure was obtained without any additional expenditure of work in driving the fan. It was in fact the equivalent of the energy of motion in the fluid leaving the disc. That was the reason that a large casing was advantageous; and perhaps the best form of fan was that which had blades inclined at their inner ends at the proper angle, and radial at their tips, but with a large enclosed casing, in which a free vortex could be formed, from the circumference of which the air was taken off.

Mr. Briggs, in reply upon the discussion, said that the fans of four or six vanes, with flat radial blades, enclosed by parallel plate sides, and with scroll or geometric spiral casing beyond the blades, were fair examples of fans as constructed for foundry purposes fifteen or twenty years since. That form of construction had for its object the delivery of the air tangentially from that point of the casing where the spiral convolution was completed.

The spiral shape of the casing was based upon the assumption, that from each space between a pair of blades a thread of air would emerge, of exactly the magnitude or volume necessary to supply the eccentricity of the casing. That assumption only held good when some definite proportion subsisted, between the pressure due to the velocity of the blade, and the pressure of resistance to discharge through the aperture of the casing, or duct beyond. As the sectional area of the discharge duct shown in Mr. Cowper's diagram (Fig. 7), and generally used, was much smaller than the sum of the spaces between the blades at their extremities, it followed that the air between each pair of blades was discharged and compressed into the expanding space of the spiral casing, and rotated with the blades, until the outlet for delivery was reached, when as all the air thus just compressed and put in motion could not pass out of the aperture or duct, the surplus was actually expelled towards the centre of the fan and discharged itself at the mouth. The same would happen if the sectional area of the discharge duct was made amply large for unrestricted discharge, whenever by length of duct, by abrupt turns or enlargements, or by closing the duct, the pressure in the duct exceeded that incident to the velocity of the fan. The proximity of the corner of the scroll to the blades also produced the noisy vibrations generally noticed in fans of this class. These conditions must occasion much loss of economic effect.

Referring to the Table (page 298) of experiments which showed a final column of useful effect of from 41 per cent. to 75 per cent., Mr. Briggs said that, in experiments upon fans of a similar kind, he had not been able to arrive at the larger values. He thought that the high results obtained by Mr. Cowper were obtained by estimating the velocity of the emerging air by indications of a pressure gauge; but there were many difficulties and sources of error in this method of determining the velocity of a current. The direction which the mouth of the syphon forming the instrument occupied with regard to the current of air was a source of uncertainty in its indications. The ordinary fountain, or *jet d'eau*, was an example of a flowing column of water, which, with corrections for friction of aperture, rose to the height of the source of supply; yet such a column exhibited no outward pressure whatever along the side of the jet. Again, if the mouth of a tube was opposed to the flow of a current of water much larger than itself, the water would be found to rise to nearly twice the height in the tube. The pressure of air in a pipe or duct during its flow could similarly be ascertained by the syphon gauge to be from less than nothing to nearly twice that really causing the flow. In the experiments he had made, reliance was placed upon anemometers of the windmill type to register the velocities

at which the air moved, and pressure gauges had only been applied where the air had been brought to rest in chambers of large magnitude as compared with the areas of the passage. With these pressure gauges it was necessary to measure more closely than by halves or quarters of inches of water column. Differential gauges with liquids of dissimilar specific gravity in the different legs, as water and spirits of turpentine, were tried; but the best results were got from the instrument now known as King's anemometer, where a float was raised, to which was attached a thread with a turn round a small barrel or spindle, to the axis of which a long arm or hand was fastened, the hand indicating on a dial the $\frac{1}{100}$ of an inch. But this instrumental exactness did not embrace all the precautions requisite. The temperature of the air and water at the instant of each experiment, and even the hygrometric conditions of the air, had to be observed, for the relative densities of air and water varied under different temperatures and states of moisture.

With all these precautions, however, the neglect to observe the pressure of the air rendered the experiments of little value; and, although an attempt was made to correct the series of observations for the barometrical and hygrometric conditions of the atmosphere, too much doubt was thrown upon them to allow of their being published. He agreed with Mr. Hawksley in the opinion that the performance of the fan terminated with that of the blade: but the opinions of Mr. Hawksley and of Mr. Cowper as to the shape of the blades were not in accordance with his views. No doubt the economic effect could be materially improved by their character and shape. His object had been to investigate the limits and conditions which governed the proportions of fans without attempting to establish a particular shape of fan or of blade. Mr. Bramwell had spoken of fans of repeated effort, and as the action of a fan was to effect a difference of pressure upon the inlet and outlet sides, it followed that one fan could be placed after another in almost endless succession.

Mr. Vignoles, President, on behalf of the Meeting, thanked Mr. Briggs for his Paper, and assured him they heartily welcomed their fellow engineers from America whenever they visited this country.

No. 1,282.—"On Recent Improvements in Regenerative Hot Blast Stoves for Blast Furnaces." By EDWARD ALFRED COWPER, M. Inst. C.E.

THE economical manufacture of iron is of so much importance, that no apology is needed for presenting a short account of some details closely bearing on the improved economy now obtained in the blast furnace, in the production of pig iron.

Up to the year 1829, all blast furnaces were blown with cold air, and the working of such furnaces was more or less irregular, depending upon a number of circumstances—one being the state of the atmosphere, as a furnace was more regular in its operation when the air was dry and frosty, than in damp weather, when it never worked well. Blast furnaces could not be made of large size when blown by cold blast, as the cold air chilled the materials as it entered the furnace.

In the year 1828, the late Mr. James Beaumont Neilson (M. Inst. C.E.), introduced the plan of heating the air employed as blast, by means of iron pipes placed in or near a fire, the air being blown through the pipes on its way from the blowing engine to the furnace. Mr. Neilson at first began with an increase of temperature of from 60° to 100° Fahr.; and even this small rise in temperature at once told upon the blast furnace, causing it to work as though it were supplied with dry air, and effecting some saving of fuel. Subsequently, Mr. Neilson improved the cast-iron pipe stoves, until a blast was obtained of a temperature of 600° or 650°; and the pipe stoves have since been urged up to 900°, and in some few cases to 1000°. The wear and tear, however, with such temperatures of blast are considerable, and great care is requisite in the management of the stoves, or they would soon melt, or be destroyed, whenever the current of cold air through the pipes is stopped, as, for instance, at the time of tapping the furnace.

It will be readily understood that, when cast-iron pipes are used for heating the blast, they must be considerably hotter than the air passing through them, or the conduction of heat would be very slow. Then again the heat of the fire, or of the products of combustion, must be considerably higher than the pipes, in order that they may be heated with sufficient rapidity to produce the necessary result. There are thus two losses by conduction (besides that through the metal itself), and the natural result is, that the

products of combustion generally pass away from the stoves at about 1250°, causing one great loss of heat, besides failing to heat the blast to the desired degree.

The friction of the air through the pipe stoves, or the reduction in the pressure of the blast (or pillar of blast as it is commonly termed) is always considerable, and the leakage of air, or loss of blast, is likewise an item with pipe stoves; and when they get out of repair, from the warping and twisting of the pipes, and consequent straining of the numerous joints, the leakage becomes so considerable, that the stoves have to be laid off for some time for heavy repairs. This is such a serious matter, that pipe stoves are often worked in a leaky condition, necessitating the expenditure of engine power for blowing air uselessly, in place of its being utilized in the blast furnace.

The stoves now about to be described are based upon the principle of the regenerative furnace introduced by Mr. Siemens (M. Inst. C.E.). The Author early appreciated the fact, that by certain new and judicious arrangements, a considerable pressure of blast might be retained in a properly-constructed stove, whilst the casing or shell of the stove was protected from the great heat of the fire, and of the blast inside it, by a fireproof lining. Thus the full pressure of air required for a blast furnace was retained within an air-tight wrought-iron skin, and the skin was kept cool by a lining of firebrick.

The principle of Mr. Siemens' regenerative furnace is now so well understood, that only a brief allusion to it will be necessary in describing the construction of these stoves. Each stove of a pair consists of a wrought-iron cylindrical casing of light boiler work (A A Figs. 1 and 2, Plate 19), having a flat bottom standing on the ground, and a dome at the top. It is lined with brickwork throughout, and is provided with a circular central shaft or flue (N), which extends to within a few feet of the inside of the brick dome. Around this shaft there are a number of compartments, or boxes (B B), formed of bricks so placed that those in one course are not exactly coincident in position with those in the courses either above or below, though a passage is left open from the top to the bottom of the mass of brickwork. Thus a new kind of regenerator has been introduced, which is supported on cast-iron gratings, at the bottom, or cool part, of the stove.

The wrought-iron casing (A A Figs. 1 and 2) is provided with several valves, three being for the admission of cold blast (E), of gas (K), and of air for combustion (L), and two being for the exit of the products of combustion (C), and of the hot blast (F). These valves are all of simple construction, except the hot blast valve (F), which has a small circulation of water through it, to keep it sufficiently cool, just as the temperature in a tuyere is kept down by

a circulation of water around it. This has always answered the purpose very well. The opening and shutting of the valves, at intervals of several hours, are matters of simple routine, and are in fact all the attention the stoves require beyond an occasional observation, to see that the stove has gas enough. There is no fear that these stoves will get too hot, as it is firebrick that is being heated, and not cast-iron pipes. Supposing, then, that a stove has been regularly at work, heating blast, and it is wished to heat the stove up again, the first thing to be done is to put another stove on, and then shut the hot and the cold blast valves (F and E) and allow the air in the stove to blow out at a small valve (c), to reduce it to atmospheric pressure. The gas, air, and chimney valves (K, L and C) are then opened, and the gas at once ignites as it enters, and gives a large volume of flame, right up the central shaft, and over and into the regenerator, thus heating the top course of brickwork considerably,—the next course, rather less, —the next still less,—and the lower part of the regenerator not at all,—the products of combustion passing away to the chimney at a temperature of about 300°. Then, as the heating goes on, and large quantities of heat are taken up by each course of brickwork, the heat penetrates by degrees lower and lower into the regenerator, until a good red heat has, in the course of several hours, reached nearly to the bottom, thus storing up a large amount of heat in the bricks forming the regenerator. The gas and the air are next shut off; the chimney valve is also shut, the cold blast is put on, and lastly the hot blast valve (F) is opened. The stove then again does duty in heating blast to full red heat, viz., a temperature of 1400° to 1500°.

All the hot blast pipes from the stove to the furnace are of wrought iron and of large size, so as to allow of several rings of brickwork lining, to prevent loss of heat.

The condition of the regenerator after it has been supplying blast for some time, and again after it has been heated, is perhaps most clearly shown by a slip of paper, coloured red nearly throughout its height on one side, with a graduated part at the bottom, shaded off to black, and on the other side coloured black nearly throughout its height, with a graduated part at the top, shaded off to red. It may be observed that the fluctuation in the temperature of the blast for two hours is only about 100° or 150°. This is not surprising when it is known, that in a little experimental stove, only 1 ft. 3 in. high, the chimney at the top was quite cool, whilst after the blast had been heated by its passage through the stove, lead could readily be melted at the bottom.

When Messrs. Cochrane & Co. adopted the regenerative hot blast stoves some years ago, at their works at Ormesby, it was at first

contemplated to use the waste gas from the top of the blast furnace for heating the stoves. On consideration, however, it was thought that the dust mixed with the gas might choke up the regenerators, as they were at that time always filled with chequered work; the bricks being so placed (Fig. 3) that in every case a brick stood over a narrow slit or passage (though a little above it), thus stopping and splitting the current of air, and effectually preventing any brush from being passed through the slit. Again, a blast of air or steam through the slit was ineffective for blowing out dust, because there existed free horizontal openings in all directions, by which the force of a blast applied to a slit was at once dispersed and lost.

Messrs. Cochrane therefore erected Mr. Siemens' gas producers, and for some years worked the stoves most successfully with gas so produced, and which contained no dust. After this, they built large brick chambers, with an extensive series of shelves inside, for the purpose of catching the dust entering with the gas from the top of the blast furnace, which was passed through such dust-catchers before being used in the hot-blast stoves. Now, however, by the use of the later improvements, invented by Mr. Siemens, Mr. Cochrane, and the Author, and embodied in the stoves just described, the cost of such dust-catchers is avoided, and the expense of producing gas is also saved, as the gas is used direct from the top of the blast furnace, and the stoves can be cleaned out with the greatest facility.

The arrangement of blast pipes, for air or steam under pressure, for cleaning out the dust from each compartment, or set of boxes, seriatim, is shown at (P) and at (Q Fig. 1). That at (P) consists of a wrought-iron pipe, jointed to a central pipe capable of revolving by a worm and worm wheel, so as to bring the pipe over each box in succession, and blow violently down it to clear out all dust. The central pipe has a slight vertical motion given to it, each time the pipe (P) is brought nearer to the centre of the stove. The blast pipe (Q), shown in dotted lines at the bottom part (O) of the stove, has a small sheet-iron cone, or umbrella, attached to it, to keep the dust off the workman when he applies the pipe to blow upwards through the boxes. The bottom part of the stove, where the cold blast enters, is always very cool, and can at any time be made quite cold, by running the cold blast through for some time longer than usual, and then a man can enter at the chimney valve at any time. The construction of the regenerator in compartments or boxes, connected together vertically, but not horizontally, gives the power of applying the blast with efficiency (inasmuch as the whole force of the blast is confined to the one passage that is being blown at the time), and admits of a good brush, like a chimney-sweeper's brush, being passed up or down

through the boxes to brush out the dust if preferred: the brush being provided with a long jointed or flexible handle.

The form and proportion of the passages have been found, after numerous experiments, to produce an excellent effect in stirring up and mixing the air passing through, inasmuch as the current is caught by the two contiguous sides of the box that overhang the one below it, and thus is, so to speak, turned over and over, first on one side and then on the other, producing a most intimate mixing of the air, and therefore quick and good conduction of heat from the hot bricks to the air, or vice versâ from the products of combustion to the bricks. It is obvious that the same surfaces that take up the heat are those that again give it out to the blast, so that there is but little loss from bad conduction; and the cold blast is thus heated to a high temperature, and the products of combustion are cooled to a low temperature, in fact nearly exchanging their temperatures, instead of the products of combustion, as in the old cast-iron pipe stoves, going away far hotter than the temperature of the blast that then obtained.

As a rule, a small stick of lead was employed as a test, to ascertain if the blast was hot enough in the pipe stoves, as it would melt the lead if hot enough; then zinc was used in like manner; but with the regenerative stoves antimony is required, and that is 'cut,' or melted, in three or four seconds. Glass rods are melted easily, as will be seen by the samples.

The results obtained by Messrs. Cochrane from the adoption of these stoves, as regards the quality of the iron, the increased make of iron, and the large saving of coke in the blast furnace, have been most satisfactory. Hitherto there has only been one drawback to the use of gas direct from the top of the blast furnace, viz., the dust, which has prevented the extensive employment of the regenerative stoves. As that difficulty has now been overcome, many ironmasters are contemplating their immediate use, and several are being erected at Barrow in Furness, of a larger size than any made previously; besides others of a smaller size at Ebbw Vale and at Pontypool.

It is a fact, however, which will be interesting to the owners of small blast furnaces, that they can, by the application of a high temperature of blast, make their furnaces equal in economy large modern blast furnaces, as is already evidenced by its application to furnaces of only 7,000 cubic feet capacity. But it must be borne in mind that large modern furnaces can also have their economy still further improved, by the application of the hotter blast. Although these stoves have been described as applicable to heating the blast to 1,400°, or more, they are equally applicable to heating blast to only 1,000°, should any ironmaster not wish to go further. They can likewise be used to heat steam or gases to a high temperature.

The results of several years' working with the old stoves, and with the regenerative stoves, have been communicated to the Author by Mr. Charles Cochrane, who has drawn out a curve (Fig. 7) showing the saving of coke, according to the temperatures to which the blast was heated. It will be seen from this curve, that about 4 cwt. of coke is saved per ton of iron, by the use of the regenerative stoves, when compared with good cast-iron pipe stoves, giving blast of 1,000°, and that the saving is larger if compared with ordinary pipe stoves, which usually give a much lower temperature.

The Author has prepared the following statement to show the comparative economy of blast of ordinary and of high temperature:

	£.
The first cost of the improved regenerative stoves for from 8,000 to 9,000 cubic feet of air per minute, at 1,400° to 1,500°, including royalty . .	3,367
The common cast-iron pipe stoves for from 8,000 to 9,000 cubic feet of air per minute, at 1,000°	4,000
The annual cost of the common cast-iron pipe stoves for from 8,000 to 9,000 cubic feet of air per minute:	
Interest at 5 per cent. on £4,000	200
Cleansing of stoves same as regenerative stoves	..
Renewal of stoves once in 10 years.	400
	£600
The annual cost of the improved regenerative stoves for from 8,000 to 9,000 cubic feet of air per minute:	
Interest at 5 per cent. on £3,367	168
Cleansing of stoves same as pipe stoves	..
Repairs	20
	£188
By the use of the improved regenerative stoves, a saving would be effected per ton of iron made, of 4 cwt. of coke, at say 11s. 6d. per ton × 475 tons per week × 52 weeks	2,840
The increased make of iron would amount to 50 tons per week × 52 weeks × say 7s. per ton profit	910
Less cost of working stoves 600 − 188	412
Increased profit per annum	£4,162

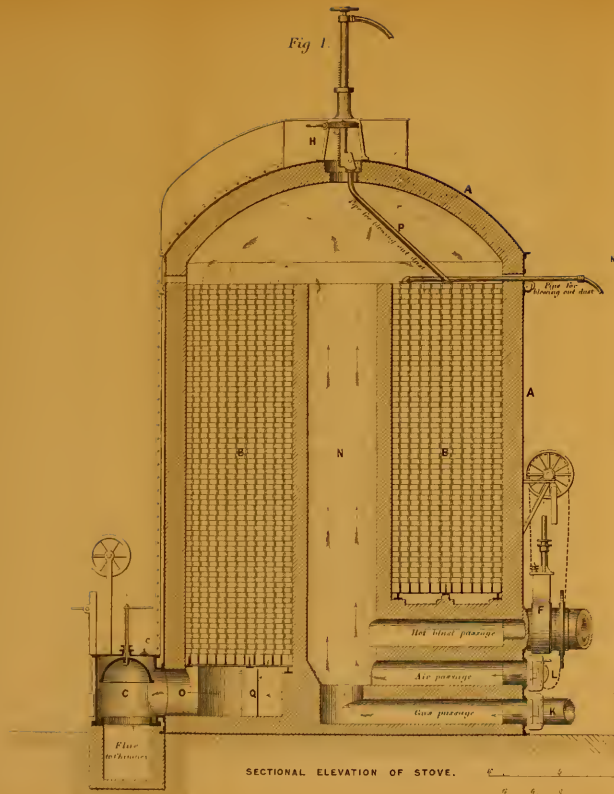
From this statement it will be seen that, with a large furnace, producing 475 tons a week, the first cost of the stoves is somewhat less than for the pipe stoves, while the annual cost of working is less, and the profit, taking the whole into account, is about £4.162 a year.

Mr. Charles Cochrane has drawn another, and a very interesting curve (Fig. 8), showing the economy resulting from the use of large blast furnaces, a matter so nearly connected with hot blast that it has been appended to this communication.

The Paper is accompanied by a series of diagrams, from which Plate 19 has been compiled.

REGENERATIVE HOT BLAST STOVES.

Fig. 1.



SECTIONAL ELEVATION OF STOVE.

Fig. 3

NEW ARRANGEMENT OF BRICKS. PLAN.

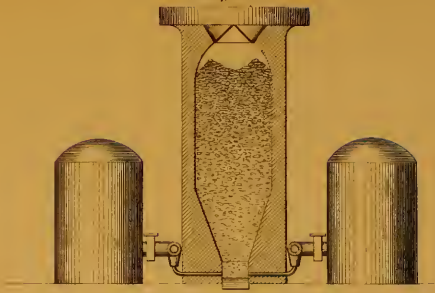
Fig. 4.

NEW ARRANGEMENT OF BRICKS. SECTION.

Fig. 5.

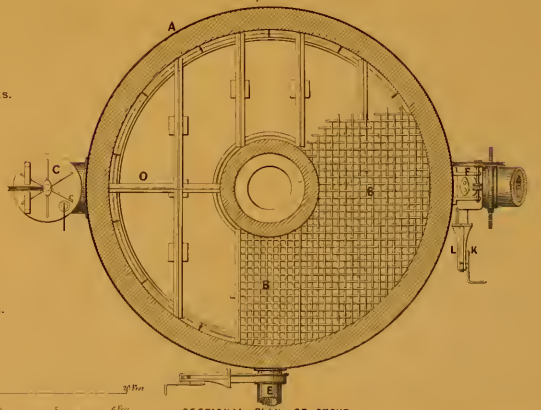
OLD ARRANGEMENT OF BRICKS. SECTION.

Fig. 6



BLAST FURNACE AND STOVES.

Fig. 2.



SECTIONAL PLAN OF STOVE.

Scale for Fig^s 1 & 2.

Scale for Fig^s 3, 4 & 5

Fig. 7.

CONSUMPTION OF COKE PER TON OF IRON MADE, WITH BLAST HEATED TO VARIOUS DEGREES.

The same Blast Furnace Ironstone, Coke and Lime were used throughout. The Ironstone containing 40 per cent Iron in the calcined state.

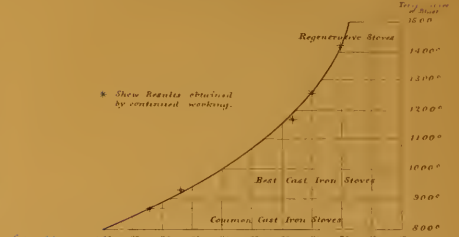
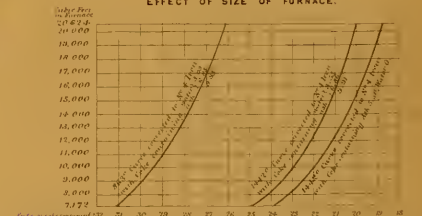


Fig. 8.

EFFECT OF SIZE OF FURNACE.



Mr. C. W. Siemens said, the apparatus described by Mr. Cowper for heating the blast differed from the ordinary hot blast stove in this essential respect,—that the same surface of refractory material that absorbed the heat from the products of combustion served also to impart heat to the incoming blast. It was necessary, under these circumstances, that there should be two stoves, or air-tight receivers, filled with the refractory materials: the one to give off its heat to the incoming blast on its way to the furnace, and the other to be heated up for continuing the operation when the heat of the first-named stove was exhausted, valves being provided for reversing the currents from time to time, as described in the Paper. By these means the same surface of refractory materials was made to take up the heat from the burning gas and to impart it to the blast; and as a consequence it followed, that the degree of heat that might be imparted to the blast was not limited by the point of safety of the iron tubes composing the ordinary stoves, but was limited only by the point of fusion of the refractory materials composing the regenerator of the new stoves. For heating blast to a moderate degree only, this stove possessed some advantages over the ordinary tube-stove, as the use of regenerators was always attended with a saving of fuel: but whenever a high degree of heat was desired exceeding 1,000° Fahr., then the tubular stove altogether failed, and the regenerative stove must be used.

The question of importance connected with this subject was, whether it was desirable to use blast of such very high temperature. Some years ago it was the opinion of practical ironmasters, that the quality of the pig metal produced was deteriorated when the temperature of the blast exceeded 500° or 600°. Now, however, ironmasters saw the advantage of raising the temperature of the blast from 600° to 800° or 1,000°; and in using this regenerative stove, the temperature had been raised as high as 1,400°, without any deterioration of the quality having been observed. At the same time, there were ironmasters of high intelligence who asserted, that though the quality of the metal was maintained, yet that there was very little or no economy whatever in increasing the temperature of the blast above 1,000°; but although this view had been gravely advanced lately, in discussions that had taken place before another Institution, he felt convinced that the conclusion in question was based upon a misapprehension, and would share the fate of the former objections to the introduction of hot blast generally.

In inquiring into the chemistry of the blast furnace, it would be difficult to separate carefully the operations going on at each stage within the vast mass of incandescent matter; but if the problem was to decide upon the goodness or the efficiency of a mechanical contrivance for transmitting power, consisting of a number of wheels, cams, and differential pulleys, there would be no very

minute inspection of the effect produced by each crank, wheel, or pulley; but the conditions of power applied to the machine would be taken, and the power judged by the motion of the load at the other end, taking it for granted that, according to the law of the conservation of force, nothing could be added or taken away except by friction. In the same way he looked upon blast furnaces. It was known that carbon, fluxing material, and ore, consisting for the most part of sesqui-oxide of iron and of silica, were put into the furnace, and atmospheric air was blown in at bottom. It was known that atmospheric air on coming into contact with carbon in a state of incandescence formed one of two combinations—viz., carbonic acid if the combustion was perfect, and carbonic oxide if the combustion was imperfect. It was known that when a pound of carbon was burned into carbonic acid 14,000 units of heat were liberated; whereas if carbonic oxide was formed, only 4,000 units of heat were liberated. It depended, therefore, entirely upon the composition of the gases resulting from the combustion in the blast furnace what would be the effective duty performed. Analyses of the gases issuing from the top of the furnace proved them to consist of about $\frac{4}{5}$ths of carbonic oxide and $\frac{1}{5}$th of carbonic acid, and if this proportion was invariable, it would be possible to say with great precision what would be the amount of heat developed by a given amount of blast of a given temperature. There were several duties to be performed by the heat thus developed. The iron oxide had to be deoxidised or reduced, and the iron had to be melted. The 'gang' and flux had to be combined and melted; and the products of combustion themselves escaped at the top at a certain temperature, which implied a loss of heat. But, without going into *à priori* calculations of these separate duties, he found that the necessary consumption of coke to smelt a ton of iron from Cleveland iron-stone, containing 40 per cent. of iron, could not be less than 19·6 cwt. This limit of economy could not be surpassed, however much the capacity of the furnace might be increased; it was the limitation which could be approached but never exceeded, except by raising the temperature of the blast to a higher point. In doing that there was heat imparted from without the furnace, which necessarily saved a similar amount of heat that had to be developed inside the furnace, by combustion of coke by means of the blast. In continuing this argument it might be thought, at first sight, that the burning of 1 pound of fuel in the stoves would save 1 pound of coke in the blast furnace; and this would really be the case, if the products of combustion of the blast furnace were carbonic acid, as in the stove; but inasmuch as the escaping gases were a mixture of carbonic acid with carbonic oxide, in the proportion of 1 to 4, the number of units of heat produced within the furnace per lb. of fuel would be reduced in the proportion of

14,000 : $\frac{4}{5}$ 4,000 + $\frac{1}{5}$ 14,000 or of 11,000 : 6,000; that was to say, the number of units of heat produced by each pound of carbon consumed in the blast furnace did not exceed 6,000; whereas each pound of carbon burned in the stove would produce 14,000 units. It was evidently, therefore, important to raise as much heat in the stove as possible, in order to save more than double the amount in the blast furnace; and when it was borne in mind, that the fuel in the stoves was obtained for nothing by burning the waste gases from the top of the blast furnace, it was obvious that there was the strongest argument for getting as much heat as possible in that way. The argument insisted upon by some ironmasters, that it would be no use to go beyond 1,000°, was based upon a misconception. They showed that each degree of extra heat in the blast produced a diminishing amount of saving in coke per ton of iron; but they lost sight of this circumstance, that the quantity of blast used per ton of iron was greatly reduced when raised to a high temperature,—the quantity of blast used being proportionate to the amount of carbon burnt in the blast furnace. In effecting, therefore, a reduction of the coke from 24 cwt. to 20 cwt., the amount of blast used per ton of iron was diminished in the same proportion, and 1° of temperature added to the blast did not represent the same amount of heat as 1° of heat communicated to blast of a lower temperature, when relatively a larger quantity was used; but if the effect of 1 unit of heat added to the blast in the stove at various degrees was taken into account, it would be found that as much saving of coke was effected in the blast furnace by adding to the blast above 1,000° as there was by adding 1 unit of heat below that limit. There was the further important saving of fuel and engine-power, in effecting an increased duty with a given amount of blast, which had been neglected in these calculations.

It would take up too much time to go further into this somewhat complex question, as it would be necessary to take into account the increased proportions of the carbonic acid gas and the lower temperature of the waste gases which resulted from high temperature of blast; but the question resolved itself into a simple one if it was looked at from a general point of view—that each unit of heat given to the blast before entering the furnace must save fuel equivalent to between 2 and 3 units of heat in the furnace, and moreover, that a much cheaper fuel was available in the stoves than within the blast furnaces.

Professor Williamson said he had felt great interest in the application of this most admirable invention of the Siemens-Cowper stove for heating air and other gases, to temperatures not hitherto attainable in practice. The application of this mode of heating gases was destined to effect in the industrial arts a revolution of which there was not at

present any conception. Mr. Siemens' proposition with regard to the particular question before the Meeting, as he understood it, was that a gain was effected in having the means of heating air to temperatures considerably above those to which it was at present heated in the blast furnace. Mr. Siemens stated that this proposition was seriously doubted by some persons of authority on these matters in the north, who denied that there was any use in going beyond what they had done. But the question was one of such importance that he thought it claimed the most careful consideration. He could only venture to submit some considerations which occurred to him from the point of view of theory; although what little he had seen of practical working bore out what theory indicated as necessary. He thought it was indisputable that a very great gain must be obtained by heating the air to temperatures beyond those to which it had hitherto been heated. It was well known that when the gases escaped from the top of the blast furnace, the only reason why they did not do more work was because the blast was not hot enough. The mixture which escaped consisted much more of carbonic oxide than of carbonic acid; but it was so cooled that it could scarcely reduce the ore. Now if that gas was taken after it had done the same amount of work that it now did, and was simply made hotter, and if it was allowed to pass over a sufficient amount of ore, it would reduce a great deal more of it; and when it left the furnace it would not be mainly carbonic oxide, but in much greater part carbonic acid. The particulars of these facts were, he thought, so well established, that he did not know there was any room for doubt respecting them. He frequently used carbonic oxide at a temperature at which it habitually left the blast furnace, as well as mixtures of carbonic oxide and nitrogen; and it was well known that the mixture would easily do a further amount of work, if only heated to a temperature higher than that to which it was habitually heated. If it did the same work as it now did when passing from a particular part of the furnace, it would proceed further on its course, and would work at a temperature capable of reducing a considerable portion of the oxide of iron to the metallic state. Therefore he thought the Siemens-Cowper stove afforded great advantages in the way of economy of fuel, even if coals were to be burnt for the purpose of heating the blast. But if, as in almost every district where iron was smelted, the gas escaping from the top of the furnace was used for heating the boilers and the blast, then the economy must be still greater.

Mr. T. R. Crampton remarked that there could be no question that the increase of temperature must be of great value. The questions in dispute appeared to be more on matters of opinion than of fact. No one could doubt that with the Siemens-Cowper stove the extra heat effected an economy of fuel. One point was lost sight of

in this controversy—viz., that the brick stove was a far better implement than the iron one, whether a temperature of 1,000° or 2,000° was required. He should hesitate to put up an iron stove if he could get a brick one at anything like the same outlay. The difficulty was not with regard to obtaining intensity of heat, as Mr. Siemens could give any intensity that might be required, but it was to get a material to withstand it. Professor Williamson would render good service, if he could discover a material to withstand heat better than the materials at present known. In experiments he had made he had exceeded the limits of any heat that could be used in the arts, inasmuch as he could melt any refractory material, even without the regenerator. He did this with cold air and cold refuse coal, the heat being absolutely regular and without smoke; but he could not give what Mr. Siemens accomplished when he cleaned his gas, viz., a perfectly clean heat, free from all dirt and dust. His own views on the subject were very crude as compared with Mr. Siemens', although he could produce sufficient heat to melt steel and even wrought iron without regeneration; but he could not produce that theoretically clean heat which this apparatus gave, and which was absolutely necessary for some purposes. He did not hesitate to say, that no one up to this time had practically accomplished with gas what Mr. Siemens had done.

Mr. E. A. Cowper directed attention to the diagram (Plate 18, Figs. 1 and 2), showing a pair of stoves as applied to one blast furnace. One stove was always being heated by the waste gas from the top of the blast furnace, whilst the other stove was heating the blast for the furnace. Sometimes two stoves were being heated, whilst one was heating the blast, as when a large volume of hot blast was required, it was more convenient to have three stoves, or more, for several blast furnaces in place of only two. The stoves were, however, now made so large, that three stoves would heat 24,000 cubic feet of blast per minute. He had received a further striking corroboration of the saving of coke by the very hot blast, which confirmed Mr. Siemens' theory as to the coke required in the furnace. A furnace having had the blast reduced to a temperature a little below 1,000°, for a particular purpose unconnected with any experiment, the consumption of coke had at once risen 3½ cwt. per ton of iron made. Again, in reference to the results obtained with blast from cast-iron pipe-stoves, a Cleveland ironmaster, by gradually raising the temperature to a high point, had in the course of seven years reduced the weight of coke required per ton of iron made from 30 cwt. to 24·75 cwt., the furnace being somewhat smaller than Mr. Cochrane's, which accounted for the amount being 24·75 cwt., in place of 24 cwt. which Mr. Cochrane's furnace would work with, when using blast at a temperature of 1,000°. Now, however,

without any other alteration than an increase in the temperature of the blast to 1,442°, the consumption of coke was 4 cwt. less per ton of iron made, or 20 cwt. only. No doubt large furnaces were more economical than small ones, from the larger quantity of iron-stone in the furnace, giving a longer time for it to be acted on by the carbonic oxide in passing through it, which thus more thoroughly and quickly deoxidized it, and prepared it for melting, on reaching the lower part of the furnace. Thus more iron was made from a large furnace than from a small one, the action was better, and the radiation and loss of heat were less. In many places it was impossible to have high furnaces, as the coke that was available was too soft and friable to bear the weight of the superincumbent mass of material. The contrast, for instance, between hard Durham coke and soft South Wales coke was such, that they were, mechanically speaking, two different materials. In such cases the economy of the small furnaces might be made to equal that of many larger furnaces, by increasing the temperature of the blast, though, of course, the larger furnaces could be made still more economical, if they also were fed by a hotter blast.

In reference to the theoretical comparison of burning fuel outside the furnace to heat the blast, in place of burning expensive coke inside the furnace, the fuel used for heating the blast outside the furnace cost nothing, as it was only the waste gas from the top of the furnace that was used to get the very high temperature of blast. This waste gas could only be used for this purpose and for heating boilers, and there was plenty of it for both purposes. If therefore this gaseous fuel was not properly burnt to realize the highest temperature, and then if the heat so produced were not thoroughly utilized, so much fuel was thrown away, for no one had yet discovered a practical way of completely converting the gas into carbonic acid, by burning and utilizing the heat in the blast furnace. In the new stoves the gas was burnt to the best advantage, so as to give as high a temperature as possible, under the circumstances; and this heat, fortunately, would not injure the bricks of which the stoves were composed, though the temperature was far too high to be applied directly to cast-iron pipes. The very surfaces that received the heat again gave it out to the blast to be heated, so that nearly the full temperature of combustion could be obtained in the blast. If an ironmaster wished to use blast at a low temperature, say 1,000°, the stoves as described were not only applicable for the purpose, but they would only be two-thirds the cost of pipe-stoves; they could not be burnt down, and the hot blast could be mixed with cold blast in any proportion, though of course the great economy of the hotter blast would be sacrificed in so doing.

The mode of preventing loss of heat, by radiation and conduction, had perhaps hardly been sufficiently explained. The outside of

the hot-blast pipes, and the outside of the stoves, were always formed of light wrought-iron plating, to retain the blast under pressure, and the plating was in all cases lined with several rings of fire-brick, so as to keep in the heat, as the iron was not capable of withstanding the heat, and the brickwork was not able to retain the blast under pressure. The hot-blast mains were, in fact, 3 feet in diameter, and they were lined with a half-brick ring of brickwork and with rings of tiles, thus reducing the passage to 1 foot 6 inches in diameter. This plan had long been found thoroughly efficient, for retaining the heat in pipes of considerable length.

The stoves designed by the Author were originally erected by Messrs Cochrane and Co., and were very economical; but to use them it was necessary either to produce the gas free from dust, by means of Mr. Siemens' 'gas producers,' or else to purify it by expensive 'dust depositors.' These, however, were now being entirely superseded by the plan of Mr. Siemens, Mr. Cochrane, and the Author, which had been described, and which was now being carried out at several large works. Thus there was put into the hands of the ironmaster an apparatus for making a greater quantity of iron, of better quality, with a given plant; and which, at the same time, saved a large amount of coke in the blast furnace.

Mr. Vignoles, President, said, there was no doubt that heating in an iron stove was the worst mode of heating. That was illustrated by a comparison of the Russian stoves with the German stoves: the former were of brick, in which the greatest amount of heat was obtained with the smallest amount of fuel; while the German stoves, of iron, were alternately blazing-hot and barely warm—even cold. Any person going into a room would be struck by the different effects produced by those stoves. This was a practical illustration, on a small scale, of the superiority of brick furnaces over iron ones.

Sir W. Fairbairn stated, through the Secretary, that he thought the most important feature in this improvement was the economy resulting from the application of the gas of the furnace for the purpose of heating. The material of the stove was also of greater durability, and he considered the subject was well entitled to the attention of ironmasters. The quality of iron had been greatly improved since the introduction of the hot blast. This arose, in his opinion, from the higher temperature of the blast, which not only tended to increase the temperature of the furnace, but raised the melting-point of the ore, and volatilised the phosphorus, sulphur, and other injurious elements, which, at a lower temperature, combined with the iron. This was certainly not the case since the blast had been raised from 600° to 900° or 1,000°; and he believed that if the temperature was increased from 1,000° to 1,500°, the quality would be still further improved, and the

value of the produce greatly enhanced. In his early investigations of the comparative value of hot and cold blast iron, he did not discover much difference in their mechanical properties; but many of the ironmasters took advantage of the discovery to remelt their old cinder heaps, and the result was a description of iron little better than pipe-clay, which gave the hot blast a bad name, and caused engineers, without further inquiry, to insist on having cold blast in their cast-iron constructions. At the present time little or nothing was said of the difference between hot and cold blast iron.

May 24, 1870.

CHARLES B. VIGNOLES, F.R.S., President, in the Chair.

The following Candidates were balloted for and duly elected :—John Bower, George Buchanan, William Janvrin du Port, James Barry Farrell, John Hill, Carl Siemens, and Robert Tyndall, as Members: John Collier, Frederick Colyer, Joseph Samuel Forbes, John Lawton Haddan, Charles Hall, Arthur Samuel Hamand, Alfred Chalmers Lawford, Matthie Charles Mackinnon, Edward Manisty, Charles Robert Manners, Angus Nicolson, Robert Pitt, John Rotheroe, Charles Edward Shepherd, Lieut., B.S.C., William Stroudley, Henry Hay Wake, and Richard Harris Williams, as Associates.

It was reported that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :—Henry Edward Roper Hoggar, Francis James Odling, and Howard John Pratt.

No. 1,247.—"On the Relative Safety of Different Modes of Working Coal." By George Fowler.

It is not likely that the working of coal will ever be an operation entirely free from danger to the workman engaged in it, for circumstances, which are really accidental, do and will occur to destroy life. There are many needful operations requiring an amount of care on the part of the workman engaged, which may probably never be general. But notwithstanding the difficulties of the question, there is reason to hope, that such material improvements will be effected in the working of coal, as to cause the death-rate to be lessened. There is encouragement for this belief, in the improvements which have taken place in the, in some respects, analogous cases of accidents by boiler explosions, which are now less numerous than in former years. A careful examination of the Reports of the Inspectors of Mines leads to the conclusion that, whilst many accidents are the result of carelessness in the details of working, the coal is in many cases so worked, that accidents are the direct effect of the method of getting it, and it is to this point that attention should be most closely turned. The subject for discussion is not whether a series of precautions, more or less necessary, are observed; but whether the mode of working the coal, and the planning, arrangement, and carrying out of that mode, are the most conducive to safety. Whether, in fact, the same amount

of caution and practical care being exercised, fewer accidents occur under one system of work than under another.

The attention of the Inspectors has hitherto been directed rather to matters of detail than of principle. It is not, perhaps, desirable that their powers should extend further. No movement of any magnitude can take place, unless it first receives the fullest professional sanction, and the hearty co-operation of mine managers and owners. Nevertheless, the reports of the Inspectors, with the accompanying plans, afford a basis for some useful conclusions.

The accidents incidental to mining are classified by the Inspectors under five heads: explosions, falls in mine, shaft accidents, miscellaneous accidents, and surface accidents. In the years 1866, 1867, and 1868, the number of casualties under these heads were:

Years.	Explosions.	Falls.	Shaft Accidents.	Miscellaneous.	Surface.	Total.
1867	154	445	132	204	77	1,012
1868	286	449	158	211	86	1,190
1866	651	361	162	203	107	1,484
Total .	1,091	1,255	452	618	270	3,686

It thus appears that the greatest mortality arises from falls, the accidents under this head amounting to 34 per cent. of the whole. Explosions have to answer for 29 per cent.; and the remaining 37 per cent. is made up by the three other classes.

In comparing the relative safety of different modes of working coal, every class of accident which may in any way affect the result, ought to be taken into consideration. The accidents by falls are the most numerous; and there is reason to think, that the mode of work may have a material effect on the mortality under this head. It is the more especial object of this Paper to prove that the same holds good in the case of explosions. The general principle of the mode of work can scarcely have any influence in the three latter classes, which require no special notice here.

Before attempting to make any comparison, it is desirable to describe briefly the principal methods of working coal. There is a great variety in the details of these methods, but they are all the practical application of two distinct principles or ideas of coal working, and may thus be divided into two classes.

One idea is to remove the coal at two operations; and this is applied in all the different methods of pillar work, as practised in the board and pillar work of the north of England, in the bank and pillar work of Yorkshire, in the panel work of Staffordshire, and in

the stall work of South Wales. In all these methods the removal of the coal is effected, more or less perfectly, at two operations. In the first pillars are left for support: in the second these pillars are more or less removed. The detailed method of carrying out this principle in the north of England is by driving headways in the solid seam, and from these the boards or working places are opened. These are set off from the headways at distances varying with the depth of the mine; the deeper the mine, the larger are the pillars left between them. When the boards are driven a proper distance, they are connected by a fresh headway, and the coal-field is thus cut up into a number of squares. The removal of the pillar, called the broken work, is supposed in the best practice to commence three or four pillars behind the working boards: practically, it is a somewhat irregular proceeding, often not begun until the mine is wholly overrun with board work.

There is a much greater variety in the practice of coal-getting in Lancashire, as the plans (*vide* Plate 20) illustrate, but the same idea of treating the roof runs through all.

The principal method of getting coal in Yorkshire appears at first sight to be very different from the foregoing, but in the treatment of the roof it is practically the same. Pairs of rise boards are set out from the level, and between these, leading and following up banks are worked, which are supported by the pillars on each side of the boards. If the pillars are removed, it is effected by working them back from the top.

The leading idea of long-wall work is to effect the entire removal of the coal at one operation. This is effected either by driving a pair of stalls on the level course, and opening off the rise stalls from the upper side of these, or by driving levels in solid coal, and opening off from what is called the opening head, or upper level. As the faces advance, pack walls of roof rock or bind are built up at regular distances along the faces, and when a sufficient width of opening is obtained, the roof settles down with or without fracture upon these packs. The roadways for the conveyance of coal are set out between pairs of packs, and as the roof settles down and squeezes them close, the roof is cut away to give the necessary height. A main goaf road, when remote from the face, has usually its full height taken out of the roof, the pack walls being buried underneath.

The working of coal on principles so diverse can scarcely fail to affect the safety of the workmen engaged, both as regards explosions and falls of roof. It is indeed possible that one method of work may be especially liable to one class of accidents, and free from the other, and thus the balance of advantages might go far to neutralize the pre-eminent safety of either. If for no other reason, it would on this account be undesirable to confine this Paper solely to the question of accident by explosions.

It will probably be conceded, that accidents by falls of roof or of coal are easily brought to the test of figures. In every coal-mine there must be the danger of accident from this cause, and although much depends upon the height of the seam, and the nature of roof, variations of this character are common to every coal-field, and hence exercise no general effect.

The following Tables, showing the number of lives lost by falls of roof, are compiled from the returns of H. M. Inspectors for the years 1866, 1867, and 1868. The comparisons are made on the number of deaths arising from these accidents; those in Yorkshire, the north of England, Lancashire, and South Wales, being credited to pillar workings; and those in Derbyshire, Nottinghamshire, Leicestershire and Warwickshire, to long-wall workings.

TABLE of ACCIDENTS from Falls of Roof and of Coal for the Years 1866, 1867, and 1868, in Pillar Workings.

Years.	District.	Number of Accidents.	Coals raised during the same time.
			Tons.
1866	Northumberland	33	10,763,800
,,	South Durham	23	14,930,000
,,	Lancashire	25	6,774,000
,,	Ditto	37	8,000,000
,,	Yorkshire	29	9,450,000
,,	South Wales	49	9,376,443
,,	Monmouth and Gloucester .	38	6,000,000
		234	65,294,243
,,	Derbyshire, Nottingham, and Leicestershire	26	7,600,000
1867	Northumberland	31	11,005,500
,,	South Durham	29	15,442,000
,,	Lancashire	30	6,844,000
,,	Ditto and North Wales . .	53	8,350,000
,,	Yorkshire	41	9,850,000
,,	South Wales	67	9,092,300
,,	Monmouth and Gloucester .	39	6,500,000
		290	67,083,800
,,	Derbyshire and Nottingham .	25	7,600,000
1868	Northumberland	30	11,400,000
,,	South Durham	36	15,300,000
,,	Lancashire	33	7,053,000
,,	Ditto and North Wales . .	62	7,600,000
,,	Yorkshire	36	9,705,000
,,	South Wales	49	9 000,000
,,	Monmouth and Gloucester .	44	6,200,000
		290	66,258,000
,,	Derby, Nottingham, Leicester and Warwick	24	7,699,000

Summary of Accidents from Falls in Pillar Workings.

Years.	Number of Accidents.	Coals raised.	Number of Tons per Life.
		Tons.	
1866	234	65,294,243	
1867	290	67,083,800	244,024
1868	290	66,258,000	
Totals	814	198,636,043	..

Summary of Accidents by Falls of Roof or of Coal in Long-wall Workings.

Years.	Number of Accidents.	Coals raised.	Number of Tons per Life.
		Tons.	
1866	26	7,600,000	
1867	25	7,600,000	305,320
1868	24	7,699,000	
Totals	75	22,899,000	..

It thus appears that, in the board and pillar districts, the proportion of accidents from falls is more than it is in the long-wall districts; and that, whilst 814 lives were lost by falls in raising 198,636,043 tons of coal by pillar working, or 1 life to every 244,024 tons, there is a possibility that the same weight of coal, if worked by long-wall, would have entailed the loss of only 650 men: a balance of 164 in favour of long-wall. It will be observed that, in these calculations, certain coal-fields, in which an amount of coal is raised equal to about $\frac{3}{10}$ths of the produce of the whole kingdom, have been excluded. In North Stafford, Cheshire, and Shropshire both modes of working coal are adopted. This is also the case in the Scotch districts.

In South Staffordshire, the mortality from falls is exceptionally great, as will be seen from the following Table (p. 328). In this district the coal is worked by both methods; but the great mortality occurs in the thick coal, which is extracted by pillar working. In Mr. Baker's Report for 1868, of the 58 deaths from falls, 36 occurred in the thick coal, 9 in thin mines worked on the long-wall system, and 12 in mines the character of which is not specified. Dividing these latter cases proportionately, 45 deaths from falls may be charged to pillar work, and 13 to long-wall work.

Years.	Number of Accidents.	Coals raised.	Number of Tons. per Life.
		Tons.	
1866	52	10,300,000	
1867	60	10,268,000	179,223
1868	58	9,900,000	
Totals	170	30,468,000	..

It is, however, still impossible to arrive at the proportionate risk, as the tonnage of coal wrought in the different mines is not given, and it is therefore best to exclude this coal-field from the calculation.

It may possibly be objected, that the quantity of coal raised in Derbyshire, Nottingham, and Leicester, is too small to allow of a fair comparison being made with the other coal-fields. This objection has a *primâ-facie* soundness, but it happens, as a matter of fact, that many seams of very varied thickness, and with very weak roofs, are worked in the three coal-fields which form the district. In one of them the same thick coal which proves so exceptionally fatal in South Staffordshire is worked by long-wall, and does not there prove so dangerous. It is, therefore, fair to conclude, that this great variety of coal-seams, varying in thickness from 2 feet to 30 feet, lying at all inclinations between 1° and 45°, and with every variety of roof, does give a sample not only of every kind of seam in the kingdom, but also of the applicability of this mode of work to all of them.

It remains to point out the reason of the comparative freedom from accident by falls with which long-wall work may be credited. The possibility of a fall of roof must necessarily increase with the width of the opening. In all pillar workings the width of these openings is large, 5 yards or 6 yards being the ordinary width of a board. In long-wall faces the working width rarely exceeds 2 yards. The soundness of the roof of a pillar mine also depends very much upon the proportion which the area of the pillar bears to the area wrought. An under-sized pillar of coal not only fails and crushes down, but, as it concentrates the superincumbent weight upon a small area, it is forced down into the underlying strata. Under the influence of their own enormous mass, the strata of a coal-field exhibit wonderful plasticity, and it is clearly proved that rocks beneath a coal-seam are frequently affected by the coal-workings above them. Mr. Buddle noted a striking instance of this in the High Main seam at Wallsend, where a thin seam was

cut through by a number of slips or hitches immediately beneath the edges of pillars left in a thick seam 15 yards above it. A case of this kind could scarcely occur affecting in a greater degree the rocks overlying the coal. Suppose, for instance, that the pillars left are of irregular shapes and areas; the subsidence must then be irregular too, and this irregularity must have a considerable effect in fracturing and weakening the roof of the coal-seam. In a case which came under the Author's notice in South Wales, the ill effect of under-sized pillars was clearly proved. On examining a colliery, a complaint was made by the agents of the badness of the roof, and of the quantity of timber which was consumed in keeping the mine open. It was also remarked that a certain district of the mine was extremely troublesome on that account. The seam was 9 feet in thickness, but 2 feet or 3 feet of the upper part of it was not worked, thus giving that which is generally found the most manageable, a coal roof to the workings. An inspection of the plan threw light upon the matter. The mine was 900 feet deep, and a large area of coal had been worked with small and irregular pillars. The principal roadways were also badly supported; whilst that part of the mine which was said to have an exceptionally bad roof was under a mountain 600 feet high, making at that point the thickness of the superincumbent strata 1,500 feet, and the weight of it 750 tons per square yard. The mine was, in fact, in a state of chronic creep, than which nothing can be more costly and dangerous. A piece of roof, sound one day, would be jointy and broken the next,—a fruitful source of mining casualties.

It may be thought that in long-wall mines, the constant settlement or bending down of the roof is attended with danger, but, practically, this is not the case. If fracture occurs it is not followed by the running down of a number of loose fragments, but by a massive settlement. This takes place gradually, and is accompanied with so much sound, that ample warning is given. When it occurs, the stall or working face is said to be 'on the weight,' and all the workmen retire. Then, again, a long-wall face is always working under a new roof, and there is no time for atmospheric action to weaken the roof of the mine.

No method of working coal is independent of precautionary measures against explosions. Every mine, if it gives off explosive gas, must have a ventilating current to remove the gas. If it be liable to give off a quantity of gas abruptly, the safety-lamp and the absence of gunpowder are necessary. That system may, however, be considered the best, which permits the most perfect ventilation, which is least subject to the chance of a local failure of ventilation, in which the discharge of gas can be best regulated and large accumulations prevented, and in which the superintendence of the workmen can be most thorough. If it can be shown that with the

same amount of ventilation, and what may be called general care, the chances of safety under two systems of work vary as 2, 3, or 4, to 1, a great point is gained.

On a perusal of the Inspector's Reports, it cannot fail to be apparent that, in nine out of ten of the smaller accidents, those in which from one man to ten men were killed, the ventilation was limited, and the presence of gas might either have been known or anticipated. The earlier Reports are full of instances of this, while those for 1864[1] and 1868[2] establish the same thing. Whilst the general care and discipline are lax, no improvement in the method of working coal can be expected to put an end to such cases. There must be in every mine cavities in the roof, or headways in the coal, which are out of the ordinary course of the ventilation, and which require constant watchfulness to keep them clear of gas. If the number of these weak points can be reduced, the chance of safety is proportionately increased. In the larger accidents it is often not easy to arrive at an explanation, as the effect of them is frequently to destroy the evidence of the cause. There can be no reasonable doubt, that some seams of coal are liable to give off large quantities of gas abruptly, and in such quantities that no ventilation can immediately dilute it. In some cases, however, the gas has been fired, and its very purity has prevented a violent explosion.

Every crevice in a gassy seam gives off firedamp, and the volume of it varies as does the flow of a river with the area of its watershed. If the crevice be a long one, as in the case of a fault slip, much gas may be expected. Still there is scarcely a case of a large explosion in which there is not evidence of a previous foulness of portions of the mine; so that, although ignited first at a blower, the explosion has been extended and made terrible by gas already present in the mine. If the normal state of the return air current of mines shows 2 or 3 per cent. of gas, the danger of this being increased to 6 or 7 per cent., with change of weather, derangement of doors, &c., is much greater than if there is no perceptible trace of gas.

Take, again, the case of the effect of barometrical changes on the safety of a mine. There can be no doubt that a fall of pressure will expand gas lying in goaves, and will increase the discharge of gas from solid coal; but that coal-mine is in a sad plight, in which during a fall of pressure there is much increase of danger, although it would appear that some mines are during one half of the year exposed to great danger. It cannot be an insignificant point for consideration, how coal can be worked so that barometrical changes are least to be feared.

Much ingenuity has been shown in improving and perfecting the

[1] *Vide* pp. 31, 124, 144.

[2] *Vide* pp. 29, 46, 67.

safety-lamp, and in substituting machinery for the use of gunpowder. It is a matter of no less consequence that coal should be so worked, that the discharge of gas may be most manageable and regular, and that accumulations may be prevented. In making this inquiry, on the effect which the mode of getting coal may have upon the safety of mines from explosion, it has proved necessary to abandon arguments based on figures and percentages. Not that if these were adduced they would be found inconvenient, but it is felt that there is so great a divergence of conditions in the different coal-fields that figures would prove little. It is, therefore, necessary to fall back upon general reasoning. Every seam of coal may be supposed to be more or less impregnated with firedamp. No two seams possess the like quantity, and in the same seam, in different localities, the quantity may, and does, vary greatly; but it is possible and desirable to associate the idea of explosive gas with the idea that in a given area it is a finite quantity, and that two equal adjacent areas contain equal quantities. Looking at it in this way, the idea of measure or quantity may be extended from given areas of seams to given quantities. Each ton of coal as it lies in the ground may be supposed to contain a certain number of cubic feet of free hydrogen; and though this number may, and does, vary, it is reasonable to associate the idea of measurement with the gas contained in each ton of coal as it lies untouched and covered up with beds of rock and shale. When, however, a shaft is sunk to an unwrought seam, a new state of things sets in. The hydrogen which is contained in the coal at a pressure greater than the atmosphere is found to be capable of movement laterally in the seam, and thus flows to the point of opening; and the rapidity with which a given area is thus drained no doubt varies in some proportion with the initial pressure of the gas contained in it, and with the texture of the coal seam. The rapidity of this drainage will also be found to vary much as it is 'boardways,' or 'endways' of the coal. In all probability it will be found to be three or four times greater on the end of the coal, as the cleavage planes are to some extent channels for the passage of the gas. Thus, in a headway on the end of the coal, the discharge of gas is most abundant at the back of the heading; if it is boardways, it is most perceptible at the sides of the heading. A boardway probably lets off a large part of the gas in the coal a considerable distance on each side of it. When the excess of pressure is relieved, the discharge may be supposed to vary with the changes in the barometrical pressure.

It is unfortunate that no experiments have been made in different localities to ascertain: (1.) The quantity of gas given off per square yard of freshly cut surface. (2.) To what extent this varies on the 'face' or 'end' of the seam. (3.) In what ratio

this discharge diminishes with time of exposure. (4.) To what extent barometrical changes affect the discharge of the gas. (5.) By what amount the pressure of gas increases as measured from an exposed surface, inwards to the solid seam. All these are points which are worthy of experiment, and their value would not be impaired by the fact, that widely different results would be obtained. It is at least desirable that the epithets 'gassy,' and 'very gassy,' should have an accurate value assigned to them.

It is much to be regretted that no experiments of the character above indicated have as yet been made. When they are made they will no doubt show that from 50 to 75 per cent. of the gas contained in the coal lying 10, 20, or 30 yards to the right and left of a boardways heading is liberated when this is driven. Thus it is ascertained that the pressure of gas in a solid seam frequently exceeds three atmospheres, and as two-thirds of this must escape to bring down the pressure to one atmosphere, which is the pressure at which it is found in the immediate vicinity of workings, it may be assumed that a boardways heading liberates at least 50 per cent. of the gas contained in the coal for a width of say 20 yards on each side of it as the headway is in process of extension, and that 25 per cent. of the remainder is gradually withdrawn by the alternate rise and fall in the atmospheric pressure. It has already been remarked, and is, indeed, self-evident, that the amount of air circulating a mine in any given time should bear some proportion to the quantity of gas discharged. All other things being equal, the greater the dilution, the greater the safety. If the gas were given off only from coal actually hewn, the mode of work would signify little, if the amount of air circulating was the same in all cases; but if the gas comes, not only from hewn coal, but also from the solid seam, it is a fair deduction that the less the surface exposed the less will be the fouling of the current.

For instance, supposing a headway, 2 yards in width, to be driven in a 3-feet seam, 10 yards on the board or face, then all the gas will be liberated in 20 cubic yards of coal, and 50 per cent. of the gas in $20 \times 10 \times 2 = 400$ cubic yards of coal, or 11 times the gas properly belonging to the coal hewn.

In a heading 5 yards wide, driven 10 yards, the gas liberated will be—

$$5 \times 10 = 50$$
$$20 \times 10 \times 2 \times \cdot 50 = 200$$

250, or 5 times the gas originally lying in the coal hewn.

In a long-wall face 100 yards in length driven forward 10 yards the gas liberated will be—

$$100 \times 10 = 1{,}000$$
$$20 \times 10 \times 2 \times \cdot 50 = 200$$

1,200, or only $\frac{6}{5}$ths of the gas lying in the coal hewn.

It will be seen that the argument holds equally good even if lower values are assigned to the discharge from the solid coal; and it may, therefore, be fairly assumed that every mode of pillar working liberates three, five, or ten times more gas per ton of coal hewn than is liberated in long-wall mines. If, therefore, the diluting power of the air current must be the same in both cases, three, five, or ten times more volume will be necessary in pillar than in long-wall mines.

In a mine which is at the present time under the Author's charge, this excessive discharge of gas in pillar roads is very noticeable. Long after a headway is driven, the gas oozes out of the sides of the headway, and may be heard at a considerable distance.

In the long-wall faces this is not perceptible, the gas which comes off there being proportionate to the coal hewn. But over and above the discharge before referred to, which is assumed to take place soon after the surfaces of coal are exposed, there can be no doubt that every superficial yard of exposed surface of coal is subject to a slight discharge on a lowering of the atmospheric pressure.

The following Table, estimated from plans Nos. 1—8, shows the area of coal surface actually exposed, and the area which would have been exposed had the mines been worked on the long-wall system:

No.	Coal worked.	Surface exposed.	Surface exposed by long-wall.
	Acres.	Square Yards.	Square Yards.
1	80	150,000	10,000
2	60	120,000	8,000
3	25	25,000	4,000
4	15	20,000	3,000
5	15	60,000	8,000

It is unnecessary to multiply instances of this kind; they are sufficient to prove that, in pillar mines, the surface of exposure is from six to fifteen times greater than it is with an equal area of extraction in long-wall mines: or, in other words, that pillar mines

are from six to fifteen times more subject to the effects of changes in the atmospherical pressure than are long-wall mines.

The mere question of the surface of coal exposed does not, however, exhaust the question. It may reasonably be supposed, that the safety of a mine will vary somewhat with the proportion which the volume of air passing minute by minute through the mine bears to the cubic contents of open mine. The open parts of a mine are, on the long-wall system, the working roads and faces, and in pillar mines, the boards and headways. The goaf room is not at present taken into consideration, as it is not supposed to be ventilated.

The following Table shows the relative cubic contents of the mines in the above-mentioned cases, as compared with long-wall mines of equal area :

No.	Cubic Contents of Boards and Headways.	Cubic Contents of Long-wall Goaf Roads and Faces.	Relative Proportion.
	Cubic Yards.	Cubic Yards.	
1	300,000	20,000	15 to 1
2	200,000	15,000	13 to 1
3	100,000	6,000	100 to 6
4	60,000	3,000	20 to 1
5	100,000	5,000	20 to 1

It is not maintained that the safety of the two methods is in the proportions given above, but a glance at the diagrams will show that, whilst in the case of long-wall mines every open part can easily be made a channel for the air-current, in the pillar mines there are an infinite number of what may be called dumb points, that is, places where there cannot be a through current.

It is frequently maintained that the law of diffusion does not obtain, or at least has but a trivial action in underground operations. Is it not rather a subject for wonder and astonishment that unventilated places are so frequently cleared by its agency? In the north of England, if the roof of the back boards will stand, the return air is coursed through them ; if not, they are shut off, but in such a manner that the air always presses on them from the working road. This prevents the irruption of gas into the working places, but it does not bring about its entire removal. There are also, in these modes of pillar work, what may be called working objections. Every fresh board and headway is driven in advance of the air-current, and thus requires special ventilation, by means

of bratticing. If the number of these boards be considerable, which it must be in a large mine, the chance of neglect is greatly increased, and many small accidents arise on this account.

It must be admitted that there are advocates for the principle of cutting a coal-field through and through, for the sake of producing some of the results which are here deprecated. Before, however, such a scheme is suggested, it should be shown that the ventilation can be made to keep pace with the increased demands upon it. The gas which is liberated and swept away one day cannot be in the mine to explode the next; but as the ventilation of a mine is, or ought to be a regular quantity, with, if anything, a slight increase as the mine becomes larger, it is doubtful policy to overload the air at one time with gas, for the sake of reducing the quantity afterwards.

Before any balance can be struck in favour of one or other mode of getting coal, it is necessary to consider how it deals with the goaf, or the place where the coal has been wholly extracted. There is a disposition amongst mining Engineers to look upon the goaf as an insoluble difficulty, and it must be confessed that in some cases there has been reason for the opinion. The prevalent idea is that it is an unventilated, ever-increasing void full of explosive gas, liable at any time to be brought out by a fall in the barometrical pressure. It is not within the scope of this Paper to suggest any novel mode for the treatment of the goaf, but merely to show under what method of getting coal it is most manageable. The subject really resolves itself into two questions: Which system gives the least goaf room? and in which is there the least danger of a discharge of gas into the workings? On the removal of a small area of coal, the overlying rocks bridge over the opening and rest upon the surrounding coal, but with an increasing area of extraction, the rocks begin to bend and sink in the middle of the opening, and this tendency increases as the square of the width of the opening. There is also a tendency for the rocks to shear along the edges of the area of extraction, and this diminishes with the length of the boundary line. It thus follows that the form of opening which most facilitates settlement is a square, because it at the same time gives the greatest width of opening and has the smallest length of boundary line. It has also the advantage of affording straight lines of fracture. It is in a long-wall face that this condition is realized, where the whole of the coal is removed over large areas; and this removal takes place by successive enlargements on one side, or by taking off a series of strips, which in the majority of cases are in straight lines. There are thus afforded the most favourable circumstances for the fracture or bending of the roof, and consequently for the formation of a close goaf.

In pillar mines circumstances are not so favourable for the

formation of a close goaf. There is always a tendency to make a number of small goaves, as may be dictated by local convenience, and to this the diagrams bear testimony. The boundary lines of these goaves are not straight, so that regular settlement is not facilitated. If two or more of these goaves are laid together, their compactness is prevented by the previous irregular fractures, and also by the small ribs and pillars of coal which are often unavoidably left in the midst of them.

But, apart from the question as to which system leaves the least amount of goaf room, there has to be considered which admits of the nearest approach to goaf ventilation? It is to a certain extent possible to bring this about in any mine, if a return air-way be maintained at the back of the goaf. Suppose, for instance, that a set of pillars are being worked off as in Fig. 11, Plate 20. The main current flows along the edge of the pillars, but there is a slight flow through the goaf to the air-way, which if sufficiently ample will compel the gas given off to pass away in that direction. This however necessitates the maintenance of an air-way at the back of every goaf, a condition which is not realized in practice; and as the goaf becomes larger this ventilation becomes enfeebled.

But the weak point of a goaf is not so much the remote part of it, where if large areas are extracted it is squeezed close, as the edge, where the roof, in the act of bending or breaking down, and partially supported by the solid coal, contains open spaces where gas may harbour. If these portions of the goaf are full of gas, a sudden fall forces it out, and hence the danger. There are indeed two places in which gas may lie on the edge of the goaf, between the packs under an upstanding roof and in the fissures formed by falls.

In the removal of pillars, the current of air has its inlets and exits in pillar roads. In Fig. 10, Plate 20, it will be observed, that the current which is forced up to the edge of the goaf by the doors X always has a tendency to rush down the roads P P P into the return current B, rather than to circulate along the face of the goaf; by so doing the distance is shortened, and the resistances always met with in a working face are diminished. No doubt to some extent the air can be forced back into the goaf, but as in doing this it then makes a longer circuit and meets with more frictional resistance, it is a difficult matter to do this thoroughly.

In a long-wall mine, circumstances are in favour of ventilating the open goaf near the face, because it affords the shortest channel for the air. Take, for instance, a panel of six stalls, A being the intake and B the return air road, Fig. 9, Plate 20. If the intake current when it arrives at T finds a break in the roof, or an opening in the pack walls, a portion of it will push through this instead of going on to the face. By putting in the scalings at C C in the

cross road up and down currents are formed in the goaf roads, which keep up the tendency of the air to pull through the goaf. Where this method is thoroughly carried out, it is unusual to find gas in the back of the open goaf. It might possibly be anticipated that, with a long length of intake and return air roads through the goaf, there would be so much leakage that a large volume of air would not reach the faces. There is, however, practically no sensible diminution in the volume of air up to the working cross roads; thus showing how solid a long-wall goaf becomes.

There is therefore, it is believed, some reason to hope that much may be gained in the safety of mining operations by an extension of long-wall working. It is satisfactory to be able to add that, on economical grounds, it is daily gaining in favour.

It has been the endeavour of the Author to base his arguments on principles which, if not admitted, give at any rate clear propositions for discussion. Recapitulating them they are: simplicity of design, small exposure of coal surface, small cubic contents of open mine, compact goaves, and approximately perfect goaf ventilation. It may possibly be shown, that every long-wall mine is not the embodiment of the foregoing principles, and there are certainly cases in which no one of these ends could possibly have been kept in view. There can, however, be no doubt that with the increasing depths, and the larger areas of coal wrought, it is time that sound rules should be observed.

The communication is accompanied by a series of drawings, from which Plate 20 has been compiled.

APPENDIX.

Table of Circumstances connected with different

Name of Colliery.	Date.	Number of Persons Killed.	Means of Ignition.				Mode of Work.	
			Open Light.	Gun-powder.	Defective Lamp.	Furnace.	Pillars.	Long-wall.
1866.								
High Brooks . .	Jan. 23	30	..	..	+	..	+	..
Bank	Feb. 28	8	..	..	+	..	+	..
Brynn Moss . . .	Mar. 3	2	..	..	+	..	+	..
Jackfield . . .	Apr. 6	4	..	..	+	..	+	..
Garswood Park . .	May 4	12	..	+	..	..	+	..
Dukinfield . . .	June 14	38	+	..	..	..	+	..
Pelton	Oct. 31	..	..	+	..	..	+	..
Oaks	Dec. 12	361	..	..	..	..	..	+
Talk o'-th'-Hill . .	Dec. 13	91	..	..	+	..	+	..
1867.								
Pewfall	Mar. 9	2	..	..	+	..	+	..
Haughhead . . .	Apr. 15	3	+	..	..	..	..	..
Cwmpennar . . .	May 2	..	..	+	..	..	+	..
Ontwood . . .	May 8	3	..	..	..	..	+	..
Mesne Lea . . .	May 30	7	+	..	..	..	+	..
Squborwen . . .	June 17	3	+	..	..	..	+	..
Garswood Park . .	Aug. 20	11	..	..	+	..	+	..
Fenny Hill . . .	Sept. 19	2	+	..	..	..	+	..
Berry Hill . . .	Nov. 6	3	..	..	..	+	..	..
Ferndale . . .	Nov. 8	178	..	+	..	..	..	..
Silverdale . . .	Nov. 9	3	..	..	..	..	..	..
1868.								
Dearnley	May 6	2	+	..	..	..	+	..
Oldfield	July 7	..	..	+	..	..	..	..
Thrislington . .	Aug. 7	7	..	..	..	+	+	..
Swan Lane . . .	Aug. 17	3	+	..	..	..	+	..
Wynnstay . . .	Sept. 30	10	..	..	..	..	..	+
Hindley Green . .	Nov. 25	62	..	+	..	..	+	..
Norley	Dec. 21	8	..	+	..	..	+	..
Haydock . . .	Dec. 26	26	..	+	..	..	+	..
28 cases.			7	8	7	2	21	2

This Table is compiled from the Inspector's Reports

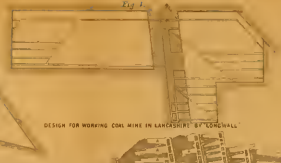
DIFFERENT MODES OF WORKING COAL.

PLAN OF PART OF A COAL MINE IN LANCASHIRE

DESIGN FOR WORKING COAL MINE IN LANCASHIRE BY LONGWALL

DESIGN FOR WORKING COAL MINE IN SOUTH WALES BY LONGWALL

PLAN OF A COAL MINE IN LANCASHIRE



DESIGN FOR WORKING COAL MINE IN LANCASHIRE BY LONGWALL

PLAN OF A COAL MINE IN SOUTH WALES

PLAN OF A BOARD AND PILLAR MINE

PLAN OF A COAL MINE IN YORKSHIRE

LONGWALL

BACK OVER

BOARD AND PILLAR

APPENDIX.

Explosions in the Years 1866, 1867, and 1868.

Locality of Accident.			Occurrence of Gas.			General Ventilation.		Local Ventilation.		
Board or Heading	Goaf.	Return.	Blowers.	Accumulation.	Goaf.	Good.	Bad.	Good.	Bad.	—
+	..	..	..	+	..	..	+	..	+	
+	..	..	+	..	..	+	..	+	..	Fall in roof; liberated gas.
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	Thirled into old workings.
+	..	..	..	..	..	+	..	+	..	Fall in roof; liberated gas.
..	..	..	..	..	..	+	..	..	..	
+	..	..	..	+	..	..	+	..	+	Doors left open.
+	..	..	..	+	..	..	+	..	+	
..	..	+	..	+	..	..	..	..	..	
+	..	..	..	+	..	+	..	..	+	
+	..	..	..	+	..	..	..	..	+	Failure of brattice.
+	..	..	..	+	..	..	..	..	+	
..	+	..	..	..	+	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	Failure of brattice.
+	..	..	..	+	..	..	+	..	+	
..	..	..	..	+	..	..	+	..	+	
..	+	..	..	+	..	..	..	..	+	
..	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	..	..	+	
+	..	..	..	+	..	..	..	..	+	Failure of brattice.
..	+	..	..	+	..	..	+	..	+	Door left open.
+	..	..	..	+	..	..	+	..	+	Failure of brattice.
+	..	..	..	+	..	..	+	..	+	
+	..	..	..	+	..	..	+	..	+	Failure of brattice.
21	2	2	1	21	1	1	18	2	21	

in accordance with dates and opinions expressed therein.

No. 1,266.—"On Coal Mining in Deep Workings." By Emerson Bainbridge, Stud. Inst. C.E.

The question as to the resources of the coal-fields of the British Islands is one of the most important of the scientific inquiries of the present day, and is one which, owing to its direct influence on the commerce and prosperity of the country, has attracted considerable attention for some years past.

In the year 1866 a Royal Commission was appointed to investigate the probable quantity of available coal remaining in the coal-fields of the United Kingdom. The report of this Commission is not yet completed, but sufficient is known, as far as the quantity of coal still remaining is concerned, to dispel the fear which has recently existed that, should the consumption and exportation of coal continue to increase in an equal rate to that of the few years preceeding 1867, the supply would fail, and in less than three centuries the coal would be exhausted.

The quantity of unproved coal remaining in the United Kingdom is doubtless very considerable; but the possibility of working it, at the great depth at which it must be expected to be found in the future, is a question not yet settled. The rate of increase of production of coal from the collieries of the United Kingdom appears, from the following figures, to have declined in the past few years, the year 1868 actually showing a decrease:

	Production.	Increase per Annum.
	Tons.	Tons.
1864	92,787,873	.. ..
1865	98,150,587	5,362,714
1866	101,630,544	3,479,957
1867	104,500,480	2,869,936
1868	100,141,157	Decrease 4,359,323

The quantities shown above would indicate a decrease in the annual production—a decrease probably due, first, to less coal being used for manufacturing purposes; and, secondly, to greater economy in the consumption of fuel, which is now being recognised as a matter of serious moment, and which in the future will doubtless exercise an important influence on the quantity of coal raised.

The duration of the English coal-fields is thus not so important a question as the production of coal of such a quality, and at such a price, as will enable England to maintain her supremacy in manufacturing industry; and, as the choicest known coal has been worked and consumed, it is evident that in the future not only the

disadvantages of increased cost of working will have to be encountered, but also the possibility of diminished value of produce. Those seams of quality which are most easily accessible will doubtless first be worked, and the country will thus ultimately have to depend upon supplies from collieries of greater depth than the majority of those hitherto sunk. It is the object of this Paper to enumerate the conditions under which coal is found in the coal-pits which are deepest at present, and to describe the circumstances and difficulties under which it may be expected to be worked in future at greater depths.

At the outset, the Author cannot but approach a subject necessarily so speculative with great diffidence, more especially since any conclusions arrived at must for the most part obviously be the result of analogous induction, rather than the comparison of actual facts relating to the question at issue; and the only justification he can plead for bringing this important subject before the Institution, is the fact that he has not only given considerable attention to the subject whilst preparing some of the evidence given before the Royal Commission, but he has had opportunities in the deepest English mines of conducting a large number of experiments, many of which have an important bearing on the subject.

It has been thought desirable to consider the subject under the following divisions:

I. Description of the localities in which deep mining will probably be prosecuted, and the position and probable extent of the coal-fields of the United Kingdom, either beyond the recognised coal-fields, or lying at greater depths than at present worked.

- *a.* Introduction.
- *b.* Notice of previous Papers bearing on the subject of the extension of the coal measures.
- *c.* Description of the map (Fig. 1, Plate 21).
- *d.* Estimate of the resources of the present and future coal-fields.

II. A brief description of the progress of coal-mining in deep workings up to the present time, with notes of the principal features of the deepest English and Belgian coal-mines.

- *a.* Introduction.
- *b.* Data respecting the depth of the chief English and foreign deep coal-mines.
- *c.* General description of plant required for, and mode of working deep mines.

III. A consideration of the chief difficulties which may be anticipated in the extraction of coal from great depths; of the manner in which such difficulties may possibly be overcome, and of

the probable greatest depth at which coal can be worked; together with an epitome of the chief data elicited by previous experiments.

a. Introduction.

b. Enumeration of difficulties which may be anticipated in working coal at a depth of 7,000 feet.

c. Temperature.

1. Scope of the inquiry as to temperature.
2. Account of experiments relating to the internal temperature of the earth.
3. Account of experiments relating to the temperature of the air in mines, and the cooling effect of ventilation.
4. Causes of high temperature in deep mines.

d. Consideration of other difficulties (beyond those of temperature) of deep mining, and the mode in which they may possibly be overcome.

1. Pressure of the superincumbent strata.
2. Working the coal.
3. Ventilation.
4. Raising the coal to the surface.
5. Cost of sinking.
6. Increased cost of production.
7. Gas.
8. Health of miners.

IV. Recapitulation of the general conclusions arrived at.

Appendix.

List of works which have been consulted in the preparation of this Paper.

I. Extension of the Coal-measures.

a. Introduction.

The universal upheaval of the strata, which occurred ages ago in Great Britain, has resulted in effecting an inclination of the rocks at an angle having a general dip or fall to the south-east, the natural consequence being that, whilst the rugged outlines of the Primary or older strata are found in the West of England, in the Midland the Secondary rocks are met with, and to the south-east the plains indicative of the Tertiary or most recent formations. It is in the Secondary, in an irregular line from the Midlothians to Devonshire, that our present coal-fields are to be found, and it need scarcely be remarked that it is only under rocks more recent than those of the Carboniferous series that the coal-fields beyond those at present known can be expected to be found, such rocks occurring for the most part to the east of the line referred to.

b. Notice of previous Papers bearing on the subject of the Extension of the Coal-measures.

The subject of the general extension of the coal-measures in Western Europe has been dealt with in a Paper by Mr. R. Godwin-Austen, published in the Proceedings of the Geological Society for the year 1856. Mr. Godwin-Austen's communication is purely geological, and treats more of the chronological relations of the different strata adjacent to the coal-measures, of their original condition, and the denudating and other forces which have caused them to be found in their present position, than of the probable area and depth of the true coal-measures. One of the chief features of the Paper is the establishment of a very ingenious hypothesis of the extension of an underground tract of Secondary rocks, ranging from the Ardennes, in Belgium, to the Mendip Hills in England, thus breaking the continuity of the Cretaceous rocks under London. Curiously enough, the results of borings for water in the south-east of England, recorded by Mr. J. Prestwich, corroborate this theory, but point out the probability of the existence of the older rocks over a much broader area than might have been anticipated.

The following are the particulars of the borings referred to:

Locality.	Date of Boring.	Depth.	Rocks passed through.	Rocks reached.
		feet.		
Kentish Town, London . .	1855	1392	Tertiary chalk .	Supposed new red sandstone.
Harwich, East Suffolk . .	1858	1302	Tertiary chalk and upper green sand	Palæozoic strata.

A boring at Calais is also mentioned by Mr. Prestwich, which having passed through similar strata to the above, met with rocks belonging to the Carboniferous series.

The Kentish Town boring reached, at the ultimate depth, rocks which could only be identified lithologically, as no fossils were yielded; but at Harwich the black slaty rock produced a specimen of Posidonyma, a shell which, with the exception of a species occurring in the Lias, is confined to the Palæozoic rocks.

It would therefore seem a reasonable deduction from the above, that, under an uncertain area of the south-east of England, the Palæozoic rocks exist at no great distance from the surface.

Mr. Hull, in his "Coal-fields of Great Britain," published in 1861, computes the area and resources of the British coal-fields, and also adds an estimate of the quantity of coal existing under the newer formations, but limits the possible depth at which coal can

be worked to 4,000 feet, a limit which was also adopted by Sir W. Armstrong in his address to the British Association in 1863.

In a Paper read by Mr. Hull before the Edinburgh Geological Society, in February, 1869, he intimated: First, the existence, as pointed out by Mr. J. B. Jukes, of a range of Palæozoic rocks, stretching from Shropshire to Leicestershire, which were never submerged during the coal period; secondly, the deposition of the Permian beds upon the millstone grit in the county of Yorkshire, north of Leeds, thus indicating the absence of the coal-measures; thirdly, that the rocks met with in the Harwich boring are of older date than the upper coal-measures; and lastly, his concurrence in the opinion expressed by Sir Roderick Murchison, at the meeting of the British Association at Nottingham, that coal would not be found under the counties east of Malvern. As there is no evidence of the Permian rocks in North Yorkshire overlying the millstone grit, no accurate conclusion can be arrived at as to the existence or otherwise of the coal-measures under this district.

c. *Description of the Map* (Fig. 1, Plate 21).

This map, which exhibits the coal-fields of the United Kingdom and the areas under which coal may be expected, or may probably exist, has been prepared partly from an examination of the sections and memoirs resulting from the geological survey, partly from a careful comparison of a number of geological maps, and partly from the writer's knowledge and observation of some of the coal-fields. The map will be found to differ in several parts from that given by Mr. Godwin-Austen, since the publication of whose paper several of the features relating to the extension of some of the principal coal-fields have been more fully proved.

On reference to the map, it will be seen that three distinguishing modes of shading are adopted, viz., black, denoting the position and area of the present known coal-fields; dark grey, denoting the area under which the coal-measures may exist within a depth of 7,000 feet; and light grey, representing the tract over which the coal-measures may possibly exist. The remaining portion of the map exhibiting the area under which the coal-measures of the Carboniferous series cannot be expected to be found.

The coal-fields of the United Kingdom amount in all to nineteen; but as several of these are small and unimportant, the following division has been adopted:

1. Durham and Northumberland.
2. Yorkshire, Derbyshire, and Nottinghamshire.
3. Lancashire and Staffordshire.
4. South Wales.

5. Small Coal Fields.
6. Scottish Coal Fields.
7. Irish Coal Fields.

The direction and extent of the possible enlargement of each of these important fields will be seen on reference to the map.

The dotted line passing westward from the north of the Thames represents the direction in which Mr. Godwin-Austen supposes the Palæozoic axis to extend.

The depth of 7,000 feet, which is rather less than three times the depth of the deepest pit in England, is taken as a limit, since the extensive area of coal-measures which will result from mining at this depth will open such large tracts of additional coal-fields, that the question of working coal at a greater depth than this need not now be considered.

The only locality in which the probable depth of the coal-measures can be calculated with any degree of correctness is that to the east of the Derbyshire and Nottinghamshire coal-fields. At the town of Lincoln, through which the line forming the eastern boundary of the supposed available coal-measures passes, the depth of the coal is estimated in the following manner: To the east of Nottinghamshire, the Permian strata are shown by the geological survey sections to have an inclination dipping to the east, of 1 in 61·3; the distance from Shireoaks colliery, which is the eastern-most colliery in the north of Nottinghamshire, to Lincoln is about 25¾ miles, or 135,960 feet, making a total fall in this distance of 2,218 feet. The depth of the Top Hard, or maincoal of Shireoaks, is 1,527 feet, and, judging from the strata outcropping further to the west, the depth to the bottom of the coal-measures will be 4,797 feet; so that, supposing the surface between Shireoaks and Lincoln to be level, as it nearly is, the estimated depth at Lincoln will be 2,218 + 1,527 = 3,745 feet, to the Top Hard coal, and 2,218 + 4,797 = 7,015 feet to the lowest part of the coal-measures.

d. Estimate of the Resources of the present and future Coal-fields.

The figures in the first and second columns of Table No. 1 have mostly been taken from the data given by Mr. Hull, with an allowance for the coal produced since it was published, whilst the rest are computed from actual measurement. It may be stated that Mr. Hull's estimate is rather lower than others more recently made.

TABLE I.

Name of Coal-field.	Present Coal-fields, to a depth of 4,000 feet from the surface.		Estimated further extension of Coal-fields to a depth of 7,000 feet.	
	Area, Square Miles.	Millions of Tons.	Area, Square Miles.	Millions of Tons.
Durham and Northumberland	460	4,700	211	1,078
Yorkshire and Derbyshire	760	8,700	6,494	43,104
Lancashire and Staffordshire	385	6,500		
South Wales	906	15,000	. .	[1]12,000
Small Coal-fields	268	2,400	. .	. .
Scottish	?	?	70	620
Irish	?	?	140	420
Total	2,779	37,300	6,915	57,222

[1] Coal-measures chiefly lying below those now being worked.

In endeavouring to form an estimate of the quantity of coal underlying the newer formations in the northern and midland coal-fields, the aggregate quantity in millions of tons per square mile, estimated as the produce of the existing coal-fields, has been divided by two, in order to arrive at the produce of the deeper coal formations—one half being estimated as lost by denudation and other contingent causes. As the extent of the South Wales basin is more accurately determined, the same proportion as that arrived at by Mr. Hull is used.

The writer trusts it will be understood that the figures in the foregoing estimate are not presumed to be even approximately accurate, but are simply presented in order to enable some idea to be formed of the extent and value of the large tracts of unproved coal, the proving and production of which must depend upon the possibility or otherwise of mining to the limit of the depth before stated. The present annual production of coal in the United Kingdom is rather more than 100 millions of tons. Allowing for an increase in this production, and taking the annual quantity of coal raised to be 110 millions, the present coal-fields may be estimated to supply the demands of the country for a period of 339 years; whilst the coal anticipated to be found at greater depths may be expected to continue the supply for a further period of 520 years.

II. EXTENT TO WHICH DEEP COAL-MINING HAS BEEN PROSECUTED UP TO THE PRESENT TIME.

a. Introduction.

The earliest mode of extracting coal from below the surface was by means of drifts or adits driven into a hillside or rising ground

wherever the "outcrop" or "basset" of a coal-seam happened to be indicated on the surface. Subsequent to this, where coal was found to exist, in localities unfavourable to the making of drifts, vertical pits were sunk to the coal, which was by this means raised to the surface. Up to within the last forty years, there were very few coal-mines in the British Islands of a greater depth than 300 yards. The first deep sinking for coal worthy of note occurred in the year 1834, when the Monkwearmouth colliery (county of Durham) reached the coal at a depth of 1,542 feet, and was then by far the deepest coal-mine in the kingdom. Since then it has been extended to a total depth of 1,740 feet.

b. Data respecting the Depth of the chief English and Foreign Deep Coal-mines.

The average depth of the English coal-mines is probably rather less than that of those of Belgium, where pits have been sunk, in several instances, to an immense depth.

The following particulars as to the depth of the Belgian mines have been taken from "Renseignments Statistiques," prepared under the direction of the Belgian Government.

Total number of coal-mines having a depth greater than

		In Belgium.		In England.
1,500 feet	..	68	..	12
1,800 „	..	33	..	4
2,100 „	..	9	..	1
2,400 „	..	2	..	1
Simon Lambert Pit .	3,489 „	..	1 (not working).	

It will be observed that at no less than sixty-eight pits in Belgium, coal is being raised a distance of upwards of 500 yards, as compared with twelve in England.

In contrasting the data respecting the deep mines in England and Belgium it may be remarked that, whilst from each of the nine pits which exceed 2,100 feet in depth an average daily quantity of 241 tons of coal is the total produce, the four Durham collieries mentioned below have each an average daily output of upwards of 1,500 tons.

The following are the names and localities of several of the deepest mines in England and Scotland:

Coal field.	Colliery.	Depth.
		feet.
Lancashire, &c. . .	* Rosebridge	2,418
	* Dukinfield	2,059
	* Ince Hall Deep Cannel	1,800
	* Lindsay Pit	1,515
	Douglas Bank	1,575
	Pendleton Colliery	1,578
	Worthington Pits	1,800

Coal-field.	Colliery.	Depth.
		feet.
Durham	* Seaham	1,524
	* Monkwearmouth	1,740
	* Ryhope	1,626
	* Murton	1,476
Derbyshire	* Annesley	1,425
	* Shireoaks	1,527
	Kiveton Park	1,203
	* Hucknall	1,250
Yorkshire	Stanley Victoria Pit	1,425
	Denaby Main	1,341
	West Riding Colliery	1,254
South Wales	Dowlais Vochriw Colliery	1,290
	* Navigation	1,200
	Dinas	1,200
Scotland	Bo'ness Colliery	1,200

The relative depths of several of the deepest sinkings and borings which have been made are shown in Fig. 2, Plate 21.

The above are the chief deep coal-mines in the United Kingdom, most of which have been sunk within the last fifteen years: the writer has had an opportunity of making an underground examination of those to which an asterisk is attached, and of conducting the experiments respecting the temperature which are afterwards recorded.

In the second section of this Paper the conditions under which some of the mines enumerated above are found are further referred to.

The Rosebridge colliery, which has attained a depth of 2,418 feet, is now the deepest coal-mine in England; but as it has recently been sunk, the underground workings are only extended for a short distance.

c. General description of the Mode of Working, and of the Plant required for Deep Mines.

Sinking Pits.

As it is now made necessary by Act of Parliament to have two separate modes of access to the workings of every colliery, all coal-mines have at least two pits or shafts, one being used as a "downcast" pit for the fresh air, and the other as an "upcast" pit, through which the air escapes after having passed through the workings of the mine. For deep mines these shafts vary in diameter from 12 feet to 17 feet, and are circular in shape; this form being the most favourable to the circulation of air. The time required for the sinking of these shafts of 17-feet diameter may be taken at about 8 yards per week, when no obstacles in the shape of water, &c., are met with; and thus a shaft 600 yards in

depth would be sunk in rather more than two years. Where a large quantity of water is encountered, at least double this time may be estimated to be required. Taking the cost of sinking at £8 per yard, the total cost of sinking two pits 600 yards would be about £9,600, or about one-tenth of the total capital required to develop the colliery. The shafts are usually encased with bricks, and, where water is met with in the strata, with cast-iron "tubbing."

Where furnaces are employed to promote ventilation, the iron tubbing in upcast shafts is generally covered with a firebrick casing to preserve it from the action of deleterious gases.

Raising Coals.

The coal is raised from mines having a depth of 600 yards or thereabouts in "tubs," each holding from 6 cwt. to 12 cwt. of coal, one or more of such tubs being placed in a cage or frame of iron, in which they are raised to the surface.

An example of the quantity of coal which can be raised at one time is afforded at Monkwearmouth colliery, where eight tubs of coal weighing $8\frac{1}{4}$ cwt. each are raised to the surface in a cage having four stories; the total weight of the cage, tubs, and coal is about 5 tons. One cage descends and the other ascends simultaneously; the time intervening between the departure from the surface of one cage and the other is about $2\frac{1}{2}$ minutes, and at this speed, with ten working hours per day, a quantity of 770 tons would be raised a distance of 1,740 feet.

The ropes used, when round, are from $1\frac{1}{4}$ inch to $1\frac{3}{8}$ inch in diameter, and when flat they vary in size from $3\frac{1}{2}$ inches by $\frac{3}{4}$ inch to $5\frac{3}{4}$ inches by 1 inch. The size of the round ropes at Shireoaks colliery (1,527 ft.) being of steel, $1\frac{1}{4}$ inch in diameter, and of the flat ropes at Seaham colliery (1,524 ft.) $4\frac{3}{4}$ inches by $\frac{7}{8}$ inch; the former having a breaking strain of about 43 tons, and the latter about 60 tons.

The engines, by means of which the coals are raised to the surface, are usually double-cylinder high-pressure engines, the cylinders of which vary in diameter from 30 inches to 42 inches, 36 inches diameter being an ordinary size for pits 600 yards in depth. At several of the Durham deep collieries, single-cylinder condensing-engines are used, the diameter of the cylinder being from 60 inches to 67 inches. The drums round which the winding ropes are coiled vary in diameter from 18 feet to 24 feet.

Underground conveyance of Coals.

Deep mines have been sunk in England to work coal from estates having an area varying from 150 acres to 4,000 acres. When the coal in large estates has to be worked by one colliery,

as is the case in the county of Durham, the underground workings are frequently taken to a distance of two and three miles from the bottom of the pit. Under such circumstances various arrangements of machinery are adopted for drawing the coal to the pit by means of ropes or chains, and where machinery is successfully applied, as in North Lancashire, horses and ponies are altogether dispensed with. In some parts of England upwards of one hundred horses and ponies are sometimes employed underground at one colliery.

Ventilation.

The airways in deep mines vary in size from 5 feet by 10 feet to 10 feet by 12 feet, and the quantity of air ventilating the mines ranges from 100,000 cubic feet to 240,000 cubic feet per minute; the latter quantity is the amount of air passing into one of the North of England collieries, and is probably not exceeded.

Mode of Working.

The methods of working the coal pursued in deep mines may be classified under two heads:

1. Long wall.
2. Pillar and stall.

The former method is adopted chiefly in Derbyshire, but is also in operation in Durham and Lancashire. Whilst in "pillar and stall" working the coal is first formed into blocks, by the driving of narrow drifts or headings, and is then all removed pillar by pillar; in the longwall system a long, straight, or irregular face of coal from 100 yards to 500 yards in length is worked all away together, and the coal is brought through passages or gateways, built up in the space whence the coal has been removed. The mode of applying the two systems will be seen on reference to the sketches, Figs. No. 3 and No. 4.

On considering the conditions which the two systems present, it will be observed that with the "pillar and stall" system, the coal, after having been formed into blocks and thus made more amenable to pressure, has to stand for some time under this pressure, until the pillars of coal are removed; on the other hand, in the working of the "long wall" system, the coal remains under the normal pressure until it is reached by the workings, when it is immediately relieved from pressure and removed altogether. The "pillar and stall" mode of working is largely adopted at Seaham and Ryhope collieries, where the pillars are made from 30 to 40 yards square. The long wall system is in use at Monkwearmouth, and at nearly all the Derbyshire collieries; at Shireoaks colliery, one straight face of coal being upwards of 500 yards in length.

III. Consideration of the Difficulties of Deep Mining.

a. Introduction.

Having endeavoured to give some idea of the importance of the question of deep mining, and having briefly noticed the circumstances under which the chief of the deep coal-mines in England are found, the consideration of the conditions under which coal at greater depths than have been hitherto reached may now be proceeded with. The real facts bearing on the question are literally hidden, and, therefore, the only mode of dealing with the question will be to collate and compare the evidence, insufficient though it may be, relating to the subject, and endeavour to deduce from it, as far as possible, practical results.

It may be stated that, as far as the present state of deep mining in England is concerned, there are no obstacles worthy of note in working coal at 600 yards from the surface, as compared with working coal, say, at a depth of 100 yards; in an engineering point of view, the difficulties, such as they are, being simply commercial, and consisting, firstly, in the increased cost of maintenance of an extensive plant; secondly, in the cost consequent upon conveying coal underground considerable distances; thirdly, in the general increased cost of production consequent on high standing charges, heavy repairs, &c. How far the influence of these causes may affect the question of deep mining is a matter which will be treated hereafter. It may, however, be stated that sufficient evidence is given of the trifling nature even of the above difficulties, by the fact that deep collieries are perfectly able to compete successfully with those that are shallow; this, perhaps, being partly owing to the large output of coal which is usually attained at deep collieries.

b. Enumeration of the Difficulties expected to be met with in Working Coal at a Depth of 7,000 feet.

As before stated, the deepest coal-mine in England is that at Rosebridge, which is 2,418 feet in depth, and is about $\frac{1}{3}$ of the depth of 7,000 feet, which it is proposed to take into consideration. It need scarcely be remarked that difficulties which can be surmounted at this depth become of less moment at a reduced distance from the surface. The estimated difficulties of coal-mining at the depth of 7,000 feet shall be chiefly considered, but some comparison may also be made between the relative importance of such difficulties at various depths.

The obstacle which has generally been recognised as the most difficult to overcome is the increase of the temperature of coal-mines with their depth; an increase attributable to several causes, which are dealt with at length in the next section.

The other difficulties, most of which may be considered of little importance as compared with temperature, are enumerated on page 342. The nature of these objections, and the possible modes of obviating them, will be considered hereafter. In the mean time, the main difficulty to be apprehended in deep mining may be approached.

c. Temperature.

1. *Scope of the Inquiry as to Temperature.*

Though it must be admitted that the experiments hitherto made as to the temperature of the strata and air in mines are so far inadequate as to lead to the opinion that much more complete observations are needed, a careful comparison of the experiments recorded here may perhaps serve to throw such light on the subject as to justify conclusions, more or less decisive, being drawn respecting the following questions:

1. The increment of increase of internal terrestrial temperature.
2. The difference in temperature between the top and bottom of a pit in different seasons of the year.
3. The difference between the normal heat of coal, stone, and other strata situated on the same horizon.
4. The length of time required to reduce the temperature of the strata by ventilation.
5. The respective powers of large and small currents of air in reducing the temperature of mines.
6. The increase in the temperature of the air due to animal heat, and to combustion from the burning of lights.
7. The hygrometric state of the air at various depths.
8. The highest temperature at which men are working in the United Kingdom, and the means of obviating its effect.
9. The distance from a face of coal, which has been exposed a certain time to a current of air, at which the normal temperature of the strata is reached.
10. The increase in the temperature of air in travelling through the workings of mines.
11. The comparative effect on the temperature of air on being carried long and short distances.
12. Amount of heat due to chemical decomposition of sulphide ores and to other extraneous causes.
13. Amount of heat due to increased density of the air.
14. The extent to which the temperature of the mine is dependent upon its relative position to the sea level.

2. *Account of Experiments relating to the Internal Temperature of the Earth.*

The experiments recorded in Table No. III. were chiefly made in the Cornish tin and copper mines. They have been carefully abstracted from the Papers in which they first appeared, and are intended to compare with other experiments, with the object of arriving at some satisfactory conclusion as to the rate of increase of temperature in descending from the surface. A uniform rate of 1°[1] increase for every 60 feet has hitherto usually been adopted. Mr. Hull bases his calculations upon an increase of 1° in temperature for every 70 feet, this being about the mean between the results obtained at the Monkwearmouth and Dukinfield collieries.

As any calculation as to the increase of terrestrial temperature to be correctly computed must have for a datum line a point unaffected by external heat, it is important to have an accurate knowledge, not only of the depth to this point, but also of the exact degree of invariable temperature.

The following Table (II.) exhibits the degrees and depth from the surface to the stratum of invariable temperature as adopted by several writers:

Table II.

Authority.	Locality.	Distance of Invariable Stratum from Surface.	Invariable Temperature.
		Feet.	°
Phillips	Monkwearmouth	10·0	47·6
R. Were Fox	,,	..	50·0
Hutchison	,,	40·0	..
Combes	Belgium	60·0	50·0
D'Aubuisson	Brittany	53·0	..
Fairbairn	Cheshire	51·0	..
Dr. Forbes	,, Trap	55·5	..
	,, Sand	65·8	..
	,, Sandstone	96·1	..
Prof. Bischoff	,,	86·0	..
Ditto	,,	25·0	..
Ditto	Prussia	155·0	..
Humboldt	,,	61·5	..
Hull	,,	50·0	50·0
Ditto	Caves d'observatoire, Paris	86·0	53·0
Ditto	Greenwich	50·0	50·5
	Average	68·9	50·23

[1] Temperature is expressed throughout this Paper in degrees Fahrenheit.

The variation of the depth at which a constant temperature is found depends partly upon the annual range of temperature, and partly upon the difference in the power of terrestrial materials at and next the surface in conducting caloric. The annual mean temperature at Greenwich is 49°·5, and that of unvariable stratum 50°·5 at a depth of 50 feet. Judging from this and from the figures in the above Table, it has been thought by the writer sufficiently correct to take 60 feet as the distance from the surface to the point of constant temperature, which may be taken at 50°, as a general standard from which to calculate.

An abstract of the results of the experiments to find the rate of increase of temperature made in Cornwall and elsewhere, and published in the transactions of various societies, is tabulated on the following page.

The following remarks may be made respecting the results shown in Table III.

1. Nearly all the temperatures recorded either refer to the water issuing from the strata at the depth stated, or to the air in contact with the rock; and, as in the Cornish mines these are generally about the same as the temperature of the strata, they may be considered approximately correct.

2. As the figures in each column represent the average of a large number of experiments, each of the temperatures shown in Column 12 will be the average probably of upwards of a hundred experiments.

3. The data given in the following Table (III.) will differ somewhat from those given in the Papers from which they have been abstracted, since such results of experiments as appeared clearly anomalous have been omitted.

TABLE III.—EPITOME of the RESULTS of EXPERIMENTS relating to the TEMPERATURE of MINES, reported in Communications to different Societies, from 1809 to 1812.

By whom reported.	D'Aubuisson.	D'Aubuisson.	Bald.	R. W. Fox.	R. W. Fox.	Forbes.	Forbes.	Moyle.	R. W. Fox.	Henwood.	Average Temperature at various Depths.	Difference in Temperature between each 100 Feet.	Feet per Degree of Increase in Temperature.	
Date.	1809.	1809.	1819.	1822.	1822.	1822.	1822.	1822.	1840.	1843.				
Where Reported.	Phil. Magazine.	Phil. Magazine.	Edinboro' Phil. Journal.	Trans. Cornwall Geol. Society.	Trans. Cornwall Geol. Society.	Trans. Cornwall Geol. Society.	Trans. Cornwall Geol. Society.	Trans. Cornwall Geol. Society.	British Association Report.	Edinboro' New Phil. Journal.			For each 100 Feet.	For the Aggregate from the first 100 Feet.
Locality of Experiments.	Brittany.	Cornwall.	North of England Coal Mines.	Cornwall.	Cornwall.	Cornwall.	Cornwall.	Cornwall. Average of a number of Experiments.	Cornwall.	Cornwall. Average of upwards of 350 Experiments.				
Distance from Surface in Feet.	Temperature.													
	°	°	°	°	°	°	°	°	°	°	°	°		
100	54·0	..	..	60·2	..	57·0	56·0	60·0	56·0	...	56·8	..	..	..
200	..	57·0	..	60·5	57·0	57·5	57·0	62·0	58·8	..	58·5	1·7	59	59
300	..	59·0	..	62·5	58·9	58·3	58·0	63·0	59·12	..	59·7	1·2	83	69
400	58·0	..	60·0	64·5	63·7	60·5	61·0	..	62·29	60·88	61·3	1·6	62	66
500	..	63·0	63·0	65·5	66·0	62·0	64·3	68·5	64·92	..	64·6	3·3	30	51
600	..	..	66·0	65·7	70·3	63·5	66·0	..	66·76	..	66·4	1·8	55	52
700	..	..	..	68·5	71·3	66·0	68·0	..	68·64	..	68·5	2·1	48	51
800	..	68·0	..	70·2	72·5	67·0	74·0	..	69·59	67·43	69·8	1·3	77	54
900	..	..	70·0	71·0	75·0	..	76·0	74·0	73·54	..	73·1	3·3	30	43
1000	..	..	..	73·0	..	70·0	..	..	73·01	78·06	73·5	·4	250	54
1100	..	..	..	75·7	..	..	..	..	74·50	..	75·1	1·6	62	55
1200	..	..	77·0	78·7	..	71·0	80·7	..	74·17	..	76·3	1·2	83	56
1300	..	..	..	80·5	..	76·0	..	78·0	..	..	78·4	1·9	53	56
1400	..	..	..	..	..	83·0	..	82·0	80·00	85·52	81·6	3·2	31	53
1500	..	..	..	..	..	..	..	84·0	..	..	84·0	2·4	42	52
1600	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1700	..	..	..	..	..	..	..	..	85·30	..	85·3	1·3	154	60

Beyond the data given in the preceding Table, the following important experiments, for most of which the Author is indebted to the managers of the collieries and others, have an important bearing on the subject, since all the temperatures have been very carefully taken in the strata.

TABLE IV.

By whom Reported.	Phillips.		Fairbairn.		Not previously Reported.						Smyth's Address, Geological Society.	
Where Reported.	Philosophical Magazine.		British Association.									
Date.	1831.		1861.		1870.		1870.		1870.		1868.	
Locality of Experiment.	Monkwearmouth, Durham.		Dukinfield Colliery, Lancashire.		Rosebridge Colliery, Lancashire.		South Hetton Colliery, Borehole, Durham.		Platt Bridge Colliery, Lancashire.		Boreholes, Torcy, and Mouillelonge.	
Feet.	Temperature.	Feet per Degree.	Temperature.	Feet per Degree.	Temperature.	Feet per Degree.	Temperature.	Feet per Degree.	Temperature.	Feet per Degree.	Temperature.	Feet per Degree
	○		○		○		○		○		○	
700	..	..	58·0	87·5	..	..	..	..	..	..	..	..
800	..	..	59·0	100	..	..	..	..	..	..	..	..
900	..	..	59·9	111·0	..	..	..	..	..	..	..	..
1,000	..	..	61·0	91·0	..	..	..	..	68·0	53·3	..	..
1,100	..	..	..	..	..	..	..	..	..	..	..	..
1,200	..	..	..	..	..	..	..	..	69·0	59·0	..	..
1,300	..	..	..	..	..	..	..	..	71·5	67·7	..	..
1,400	..	..	67·1	65·5	..	..	72·0	59·5			..	..
1,500	..	..	68·5	71·0	..	..	..	..			..	..
1,600	72·6	67·4	69·7	83·0	..	..	..	..			..	..
1,700			..	..	..	..	82·0	29·4			..	..
1,800			..	..	..	..	..	..			81·0	56·7
1,900			..	..	83·0	53·3	96·0	19·7			..	..
2,000			..	..	85·0	41·0					..	..
2,100			75·5	86·2	..	..					..	..
2,200					..	..					..	..
2,300					92·0	51·4					..	..
2,400					93·0	51·0					..	..
2,600											100·9	43·
Average	..	67·4	..	78·2	..	55·0	..	40·8	..	55·6	..	51·

In the preceding Table the temperatures given were not observed at the exact depths stated, but at depths closely approaching thereto; the 'feet of depth' per degree of increase are calculated from the actual depths and temperatures.

As experiments to find the temperature at different depths have only been made in the sinkings of the Dukinfield and Rosebridge collieries, the detailed account of the observations at each place is recorded below; the figures relating to Dukinfield are taken from Mr. Fairbairn's Paper, and those referring to Rosebridge colliery have been kindly supplied by the manager.

TABLE V.

Distance from Surface.	Dukinfield. Temperature.	Dukinfield. Feet per Degree between each Observation.	Rosebridge. Temperature.	Rosebridge. Feet per Degree between each Observation.
Feet.	°		°	
17	51·0	..	..	..
700	58·0	..	..	..
800	59·0	100	..	..
900	59·9	111	..	..
1,000	61·0	91	..	..
1,100	63·5	40	..	..
1,200	65·6	67	..	..
1,300	66·5	67	..	..
1,400	67·1	166	..	..
1,500	68·5	71	..	..
1,600	69·7	83	..	..
1,700	71·2	66	..	..
1,800	72·2	100	..	..
1,890	..	..	83	..
1,900	72·2	..	..	..
1,989	..	..	85	49
2,000	73·2	200	..	..
2,013	..	..	86	24
2,037	..	..	87	24
2,055	75·5	24	..	..
2,202	..	..	88½	110
2,235			89	66
2,283			90½	32
2,325			91½	42
2,349			92	48
2,400			93	51
2,424			93½	48

The following Table exhibits the rate of increase of temperature in sinkings and borings of different depths, and having a different relative position to the level of the sea.

The data given are partly taken from the preceding Tables, but are chiefly the results of observations kindly supplied to the writer by the Engineers by whom the experiments were made. Except in the cases taken from previous Papers, the calculations for increase of temperature have the standard of 50° as the unvariable temperature at a distance from the surface of 60 feet.

With regard to the experiments at the Welsh collieries shown in the Table, it may be said that they were conducted with especial care: the holes after being bored were allowed to stand twenty-four hours before the experiment was made, and immediately the hole was scraped out, the orifice was closed with wooden plugs covered with flannel. The thermometer was left in the hole for periods ranging from fifteen minutes to thirty-six hours, and was

inserted a distance of 4 feet; no change, on a trial being made, having been observed in the readings at distances of 3, 4, 5, 6, and 12 feet in the coal.

TABLE VI.

RESULTS of EXPERIMENTS showing the increase of Temperature with Depth, at various distances from the surface.

No.	Locality.	By whom Quoted.	Height of the Top of Pit or Boring above Sea Level.	Total Depth of Point of Observation from Surface.	Temperature at Bottom of Sinking or Bore-hole.	Feet per Degree of Increase in Temperature.
			Feet.	Feet.	°	
1	Artesian borings . . .	Arago, quoted by Greenwell.	..	184	..	52·3
2	Ditto ditto . . .	,,	..	207	..	46·4
3	Ditto ditto . . .	,,	..	216	..	38·2
4	Ditto ditto . . .	,,	..	328	..	49·2
5	Ditto ditto . . .	,,	..	361	..	40·1
6	Ditto ditto . . .	,,	..	459	..	42·5
7	Boring near Geneva . .	Hull.	1,600	724	..	55·0
8	Denby Colliery	..	..	960	62·5	72·0
9	Moira ditto	..	..	1,030	66·0	60·6
10	Cwm Neol ditto. . . .	..	840	1,150	65·0	72·6
11	Killingworth ditto . . .	Greenwell.	..	1,200	..	42·2
12	Kiveton Park ditto . . .	..	..	1,200	71·0	54·3
13	Upper Duffryn ditto . .	..	1,200	1,210	65·0	76·3
14	Hucknall ditto	..	..	1,250	70·0	59·5
15	Upper Duffryn ditto . .	..	1,330	1,400	68·0	74·4
16	New Tredegar ditto . .	..	1,287	1,549	69·0	78·4
17	Monkwearmouth ditto . .	..	101	1,584	72·6	67·4
18	Upper Duffryn ditto . .	..	1,540	1,690	75·0	75·0
19	Cornish Mines (Table III.)	From Table 2.	..	1,700	85·3	60·0
20	Tresavean Mine	Hull.	..	1,740	85·4	60·0
21	Puits de Grenelle . . .	..	119	1,795	81·9	59·0
22	Boring at South Hetton Colliery	..	470?	1,938	96·0	40·8
23	Dukinfield Colliery . .	Fairbairn.	300?	2,055	75·5	78·2
24	New Saltwerk, Westphalia boring	Hull.	231	2,281	91·0	54·7
25	Mendorff, Luxemburg; boring	..	..	2,394	..	57·0
26	Rosebridge Colliery. . .	..	200?	2,424	93·0	55·0
27	Boring at Torcy. . . .	Smyth.	..	2,676	100·9	51·4
28	'Simon Lambert' Colliery, Belgium . . .	..	..	3,489	78·8	119·1
29	Average of German mines.	Humboldt.	Not recorded.	Not recorded.	Not recorded.	76·3
30	Minden Saltworks . . .	..	,,	,,	,,	53·6
31	Average of 5 Coal-mines . 6 Cornish do. . 8 Foreign do. .	Hutchison.	,,	,,	,,	49·1

The experiments given in the preceding Table apply solely to the temperature of the earth, and the deductions which it is thought may be drawn from them are enumerated hereafter.

Having given the results of investigations relating to the temperature of the strata, the consideration of the effect which this temperature has upon the air in mines may now be proceeded with.

3. *Account of the Experiments relating to the Temperature of the Air in Mines, and the cooling effect of Ventilation.*

Nearly the whole of the experiments detailed below have been made within the last twelve months at the chief of the deepest English coal-mines. The experiments made by the writer at Rosebridge, Dukinfield, and Monkwearmouth collieries, were made with five thermometers which were carefully tested and compared. They were as follows:—One dry bulb, one wet bulb, one graduated to tenths of a degree, one maximum, and one minimum thermometer. The readings of the dry and wet bulb thermometers alone are given, together with those of an aneroid barometer.

The actual temperature of any point of observation was supposed to be reached when two readings within an interval of a few minutes gave the same results; the time the instruments were exposed varied from fifteen to sixty minutes.

1. *Rosebridge Colliery, near Wigan.*

Date of Experiment, January 11, 1870.

Depth to Arley Mine seam . . . . . 2,418 feet.
Height of seam . . . . . 3 feet 8 inches.
Quantity of air passing into mine . 30,300 cubic feet per minute.
Average temperature of the upcast pit . . . . . 130°.
Distance travelled by air, about . . . . . 560 yards.

Table VII.

Where observed.	Depth from Surface.	Distance from Downcast Pit.	Barometer.	Temperature.		Air passing, Cubic Feet per Minute.
				Dry Bulb.	Wet Bulb.	
	feet.		inches.	°	°	
Top of pit	..	..	29·53	41·4	37·7	..
Bottom of downcast .	2,418	..	32·33	54·9	50·6	30,300
,, upcast . .	..	..	32·21	62·9	56·3	..
Face of coal exposed 1 hour; had been standing previously for 16 hours . . .	..	300 yds.	32·21	77·9	69·3	1,920
Face of coal exposed 4 weeks	..	130 ,,	32·21	61·3	56·6	4,500
Face of coal exposed 14 weeks between two doors . . .	..	80 ,,	32·20	63·4	56·7	Current scarcely perceptible
Top of pit, 27th Sept., 1869	..	..	..	59·2	57·2	..
Bottom of downcast .	..	..	..	69·0	62·0	10,000
Normal temperature of coal	..	..	..	93·5	..	..

2. *Dukinfield Deep Pit, near Ashton-under-Lyne.*

Date of Experiment, January 10, 1870.

Depth of pit . . . . . 2,059 feet to Black Mine seam.
Height of seam . . . . 4 feet, rising at an angle of 45 degrees.

Observations.	Thermometers.		Barometer.	Cubic feet of Air per Minute.
	Dry Bulb.	Wet Bulb.		
	°	°	inches.	
Top of pit . . .	47·6	43·7	29·47	.. ..
Bottom of downcast	53·5	51·4	31·75	80,000 cubic feet.
,, upcast .	73·6	67·1	31·40	(250 feet above bottom of downcast.)

Consumption of fuel at ventilating furnace per 24 hours, 144 cwt.

3. *Monkwearmouth Colliery, near Sunderland.*

Date of Experiment, January 18, 1870.

Depth of pit . . . . . 2,140 feet to Hutton Seam.
Height of seam . . . . . 4 feet.
Quantity of air passing into mine . . 161,838 cubic feet per minute.
Water gauge . . . . . 4·20 inches.
Consumption of fuel per 24 hours . . 114 cwt.

The observations made are as follows:

TABLE VIII.

Where observed.	Thermometers.		Barometer.	Distance from Downcast Pit.	Air passing, Cubic Feet per Minute.
	Dry Bulb.	Wet Bulb.			
	°	°	inches.	yards.	
Top of pit	40·6	37·4	30·73	..	.. ..
Bottom of downcast	53·0	48·2	32·78	..	50,000
,, upset	79·5	..	..	..	.. ..
Coal face exposed to air 12 months	73·2	66·0	..	2,000	4,000
Wagonway (1)	83·5	76·7	..	3,100	3,000
Ditto (2)	78·5	71·7	..	3,900	4,000
Ditto	75·0	67·0	..	2,600	10,000
Ditto	73·0	63·0	..	2,230	12,000
Ditto (3)	70·0	60·6	..	2,200	25,000
Ditto	62·0	55·0	..	1,500	80,000

(1) 100 yards from face of Longwall.
(2) 200 ,, ,, ,,
(3) Air splits here.

A series of valuable observations of the temperature of the air and coal in various parts of the Monkwearmouth colliery are taken half-yearly. The manager kindly allowed the Author to have a copy of these, of which the following (Table IX.) is an abstract:

TABLE IX.

Where observed.	Experiment.	July, 1866. Average.	January, 1867. Average.	July, 1868. Average.	January, 1869.			July, 1869.			January, 1870. Average.
					Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	
		°	°	°	°	°	°	°	°	°	°
Surface . . .	Average of sun and shade.	68·0	34·8	68·5	67	40	50	75	59	70·2	49·0
1,080 feet from surface near the downcast pit .	Thermometer in hole in stone	59·2	51·4	58·7	53	51	52·8	61·5	61	61·1	54·8
	Thermometer hung in current of air . .	60·0	42·9	58·1	50	44·5	47·2	63	57	61·6	49·1
	Current of air, cubic feet per minute . .	37,895	28,654	74,388	72,243	68,805	69,743	33,700	32,850	33,275	33,611
2,200 feet from the surface, and about 1,400 yards from pit	Thermometer in hole in coal	72·6	71·8	70·0	69·5	68·5	68·8	70·5	68·5	69·3	69·5
	Thermometer hung in current of air . .	70·2	62·8	63·7	61·5	60·5	61·0	69·5	67·5	68·4	63·0
	Current of air, cubic feet per minute . .	31,245	23,512	64,957	62,146	60,192	60,610	64,532	61,950	62,803	84.141
2,150 feet from the surface, and 2,700 yards from pit . .	Thermometer in hole in coal	80·1	80·1	83·7	81·5	80·5	80·8	89·5	88·5	88·9	84·8
	Thermometer hung in current of air, 4,000 cubic feet per minute	83·0	78·3	82·1	83·0	81·5	81·8	86·5	86·0	86·2	82·5

The experiments given in this Table are of great value in displaying the effect of the surface temperature upon the temperature of the air and strata underground.

The figures given are the average of readings taken on fourteen consecutive days. The thermometers, after having been compared, remained in their position during the whole of this time, and the observations were made as nearly as possible simultaneously.

The thermometers were inserted a distance of 4 feet in the coal and stone.

4. *Seaham Colliery, County of Durham.*

During a residence of some years at this colliery the writer had frequent opportunities of conducting experiments as to temperature, &c.

Date of Experiment, June 2, 1869.

Depth of pit		1,524 feet.
Height of seam		4 feet 6 inches.
Quantity of air passing into mine	221,077	cubic feet per minute.
Ditto ascending (heated by furnace) upcast shaft	294,171	„ „
Water gauge, bottom of pit		3·65 inches.
Ditto, top of pit		4·73 „
Ditto, due to downcast shaft friction		1·08 „

The following observations are recorded:

TABLE X.

Where observed.	Depth from Surface.	Distance from Downcast Pit.	Temperature.		Air passing, Cubic Feet per Minute.
			June 2, 1869.	April 2, 1869.	
	feet.	yards.	°	°	
Top of pit	..	..	55	41	.. ..
Bottom of downcast	1,524	..	57·7	44	about 80,000
Wagonway	1,527	1,580	59·8	..	.. ..
Ditto	1,569	2,570	62·1	..	.. ..
Ditto	..	3,076	63·9	..	.. ..
Entering working face of coal	..	3,578	66·3	67	8,000
At last working place	1,536	4,572	76	76	very little air.
In return air course	1,525	2,570	76	74	.. ..
Ditto, near furnace	1,549	253	..	76·5	.. ..

An interesting experiment to find at what distance from a face of coal, which had been exposed for a number of years to a current of 65,000 cubic feet of air per minute, the normal temperature of the mineral exists, was made at Seaham colliery by Mr. Daglish, who has kindly allowed the writer to quote it.

A number of bore-holes were made in the coal to the distances

shown below, and a thermometer was placed in each hole for twenty minutes.

The following is an account of the experiment, which is shown in Fig. 5, Plate 21:

	°
Temperature of external air	59·25
Borehole 2 ft. 0 in. into coal	59·75
„ 3 „ 0 „ „	62·00
„ 4 „ 6 „ „	63·00
„ 5 „ 8 „ „	63·75
„ 8 „ 0 „ „	66·00
„ 11 „ 0 „ „	70·00

The experiment unfortunately was not completed (the normal temperature of the coal being about 74°), but as will be seen by the diagram it is sufficient to show the rate of decrease; by continuing the curve the normal temperature of the coal would appear to be reached at a distance of 13 feet.

Fig. 6 exhibits the difference between simultaneous readings of the thermometer at the top and bottom of this pit in the month of May, 1869.

5. *Shotton Colliery, County of Durham.*

Date of Experiment, January 20, 1870.

Depth of pit	1,200 feet.
Diameter	14 feet 9 inches.
Quantity of air passing into mine	198,302 cubic feet per minute.
Coals consumed every 24 hours (dust coal)	360 cwt.
Water gauge	1·88 inch.
Area of main airways	8 × 6 feet.

Temperature taken in a place driven 120 yards from the air course, and ventilated by a brattice, about 1,200 yards from the pit:

	°
At 120 yards from the face	65
70 „ „	68
20 „ „	70
3 „ „	72
At a hole bored 5 feet into the coal	73

6. *Pendleton Colliery, near Manchester.*

Date of Experiment, September 10, 1869.

Depth of pit	1,578 feet.	
Water gauge, both pits standing, *i.e.* no coals being raised	1·2 inch.	
Both cages moving—cage of upcast pit ascending	1·2	„
Ditto, upcast cage descending	0·7	„
Water gauge, due to resistance caused by cage	0·5	„

TABLE XI.

Where Observed.	Distance from Pit.	Depth below Surface.	Thermometer.	
			Dry Bulb.	Wet Bulb.
	yards.	feet.	°	°
On surface	..	..	59·7	57·8
In the return air course	3,659	1,578	75·0	69·0
Near „ „	2,285	2,064	80·0	71·0
In „ „	2,435	2,040	81·0	76·0
In „ „	3,035	2,064	81·0	75·0
Near the end of a heading . . .	1,150	2,214	76·0	68·0
In „ „ . . .	1,465	2,214	77·0	69·5
Normal temperature of coal . . .	..	2,214	80·0	..

The following experiments made at this colliery are valuable as exhibiting the difference in temperature between the coal and adjacent rock. Side by side with them are placed some similar observations taken in several Welsh collieries by Mr. F. Wilmer, who has kindly allowed the writer to make use of them.

TABLE XII.

Pendleton.				Welsh Collieries.			
Distance from Shaft.	Depth from Surface.	Temperature 4 feet in hole.		Distance from Shaft.	Depth from Surface.	Temperature.	
		Coal.	Stone below Coal.			Coal.	Stone adjacent to Coal.
yards.	feet.	°	°	yards.	feet.	°	°
..	..	..	..	27	360	61·0	61·0
200	2,214	80·0	84·0	1,587	1,210	65·0	64·0
300	1,944	75·0	77·0	1,877	1,400	68·0	68·0
400	2,214	82·0	86·0	2,327	1,690	75·0	75·0
500	1,988	70·0	74·0	27	285	58·0	56·0
1,000	1,988	83·0	82·0	1,100	680	59·0	58·0
..	..	..	..	2,341	1,120	62·0	62·0
	Average	78·0	80·6		Average	64·0	63·4

The following are the results of a series of experiments made many years ago by Mr. Henwood to prove the respective increase in temperature in various descriptions of strata. The figures express the number of feet per degree of increase in temperature and relate to mines reaching a depth of upwards of 1,200 feet:—

	Slate.	Copper lodes.	Rocks.	Zinc lodes.	Granite.
1° for every . . .	27	38	40	43	51 feet.

7. *Hucknall Colliery, near Nottingham.*

Depth of pit	1,242 feet.
Diameter	12 „

Quantity of air passing into mine :—	Cubic Feet per Minute.
Split No. 1	45,000
„ „ 2	25,000
„ „ 3	45,000
Furnace	15,000
	130,000

Length of longest split	2,200 yards.
Coals consumed by furnace per day	123 cwt.
Distance to farthest place from shaft	900 yards.
United area of intake passages	180 sq. ft.
Ditto return ditto	140 „

The following observations were taken shortly after the pit was sunk, when only 30,000 cubic feet of air per minute was passing into the mine:—

	°
Temperature top of pit	70
„ bottom of pit	58
„ „ „ 1 foot in coal	59½
„ on reaching the working face	68½
„ on leaving ditto	71

The observations recorded below were made recently:—

TABLE XIII.

Where Observed.	Distance from Pit.	Approximate Depth from Surface.	Thermometer. Clear Frosty Day. Nov. 11, 1869. Dry Bulb.	Clear Frosty Day. Nov. 11, 1869. Wet Bulb.	Dull Damp Day. Nov. 10, 1869. Dry Bulb.	Dull Damp Day. Nov. 10, 1869. Wet Bulb.
	yards.	feet.	°	°	°	°
Top of pit	..	1,242	33·5	30·5	46·0	45·0
Bottom of downcast	..	..	42·0	39·0	53·5	51·0
On wagonway	250	..	47·0	43·0	55·0	52·0
„ „	600	..	50·0	45·5	57·0	54·0
„ at this point the air is split	950	..	60·5	54·0	59·0	55·0
After passing through working	..	..	67·0	63·0	64·0	60·0
In return at bottom of upcast	..	..	65·0	61·0	66·0	62·0
„ „ in summer	..	..	69·0	..	..	..
Normal temperature of coal	..	1,242	71·0	..	..	..

	°
Temperature of upcast shaft . . . . . Top	90
„ „ „ 600 feet from ditto	95
„ „ „ 1,200 „ ditto	110

8. The following are the results of experiments made at two other collieries in Nottinghamshire:—

TABLE XIV.

	Annesley Colliery.	Kinton Park Colliery.
	feet.	feet.
Depth of pit	1,425	1,200
	°	°
Temperature top of pit	64	56
,, bottom of downcast	58	55
,, in return 10,000 cubic feet of air passing.	67	..
,, in heading 600 ,, ,,	..	72½
,, ,, 2,000 ,, ,,	..	64

9. *Shireoaks Colliery, Nottinghamshire.*

Date of Experiment, June 10, 1869.

Depth of pit . . . . . 1,545 feet.
Height of seam . . . . . 3 feet 6 inches.
Quantity of air passing into mine . 110,000 cubic feet per minute.
Average distance travelled by air currents . . . 4,500 yards.
Water gauge . . . . . 2·5 inches.

TABLE XV.

Where Observed.	Distance from Pit.	Depth below Surface.	Temperature.
	yards.	feet.	°
Top of pit	..	..	74·0
Bottom of downcast	..	1,515	61·7
Wagonway	700	..	61·0
,,	1,000	..	62·7
,,	1,220	..	64·0
,, just before reaching workings	1,625	1,590	67·0
After passing along 325 yards of working face, and over 66 men and boys, and 5 horses	1,950	,,	73·0
After passing along 500 yards of working face, and over 76 men and boys, and 5 horses	2,125	,,	73·7[1]
In return	1,000	..	73·5
In return near furnace	115	1,515	72·5

[1] It will be observed that in travelling along the working face, a distance of 175 yards, and over 10 men, the temperature of the air was not increased one degree.

The following is an abstract of observations taken in the first half-year of 1869 at this colliery:—

TABLE XVI.

DATE.	Temperature at Top of Pit.	Temperature, Bottom of Downcast.	Temperature of Return near Furnace.
	°	°	°
1869—January 10 . .	52·5	54	72
20 . .	44·5	50	72
March 10 . .	38·5	43	71
20 . .	42·0	45	71
May 10 . .	45·0	60	72
20 . .	60·0	55	71
July 10 . .	70·0	64	74
20 . .	66·0	66	74

10. *South Wales.*

The following experiments were made at various collieries situated in the South Wales coal-field, where the coal-measures are found at an unusually high elevation:—

TABLE XVII.

Name of Colliery.	Depth from Surface.	Distance from Pit to Point of Observation.	Point of Observation.			Temperature in Air Current.
			Depth from Surface.	Distance from Sea Level.		
				Above.	Below.	
	Feet.	Yards.	Feet.	Feet.	Feet.	°
Upper Duffryn . . .	360	Top of Pit.	..	400	..	76
		Bottom of do.	..	40	..	67
		27	360	40	..	62
		1,581	2,210	10	..	66
		1,877	1,400	..	70	66
		2,327	1,690	..	150	74
Lower Duffryn. . .	825	Top of Pit.	..	500	..	52
		Bottom of do.	..	..	325	63
		120	830	..	300	71
		1,020	1,269	..	285	74
		1,850	1,588	25	..	78
Cwmdare	285	Top of Pit.	..	600	..	68
		Bottom of do.	..	315	..	64
		27	285	315	..	64
		1,100	680	295	..	60
		2,204	1,120	330	..	67
New Tredegar . . .	1,295	Top of Pit.	..	720	..	43
		Bottom of do.	..	..	375	53
		110	865	..	190	60
		570	920	..	241	70
		1,370	1,673	..	180	72
		2,090	1,549	..	262	71
Vochriw	1,103	Top of Pit.	..	1,328	..	51
		Bottom of do.	..	225	..	56
		66	1,103	225	..	59
		466	1,320	256	..	59
		2,000	628	390	..	65

11. The Author is indebted to Mr. J. J. Atkinson, Inspector of Mines for the County of Durham, for several of the observations recorded in the following Table, which exhibits the temperature of the return air in thirty-five collieries. Some of the data given have been abstracted from the foregoing detailed experiments, whilst the figures relating to some of the Belgian mines are taken from those supplied to Mr. W. Smyth by M. Jules Gernaert.

TABLE XVIII.

		Depth of Point of Observation below Top of Shaft.	Depth of Point of Observation below Sea Level.	Distance travelled by the Air in the Mine up to Point of Observation.	Temperature.			Date of Experiments.
					At top of Pit in the Shade.	At Bottom of Pit.	In Return Air.	
		Feet.	Feet.	Yards.	°	°	°	
1	Vochriw . . .	628	390[1]	2,000	51·0	56·0	65·0	1867
2	Adelaide . . .	1,034	614	3,313	..	..	68·0	1869
3	Du Gouffre. . .	1,099	..	377	68·0	..	60·8	1848
4	Cwmdare . . .	1,120	330	2,204	68·0	64·0	67·0	1867
5	Murton	1,152	824	2,572	..	..	78·0	1869
6	Shotton. . . .	1,160	748	2,640	35·0	43·0	68·0	1869
7	Haswell . . .	1,170	750	6,920	..	..	71·0	1869
8	Hucknall . . .	1,242	..	1,700?	33·5	42·0	66·0	1869
9	Charbonnage Mines	1,362	..	..	53·6	..	56·7	1849
10	Du Gouffre. . .	1,368	..	1,175	68·0	..	64·4	1848
11	Annesley . . .	1,425	..	..	64·0	58·0	67·0	1869
12	De l'Espérance .	1,457	..	..	51·8	..	69·8	1837
13	Murton	1,489	1,161	3,388	..	..	72·5	1869
14	Seaham. . . .	1,524	1,320	3,914	55·0	57·7	76·0	1869
15	Monkwearmouth .	1,542	1,441	3,590	..	..	75·0	1869
16	New Tredegar . .	1,549	262	2,090	43·0	53·0	71·0	1867
17	Ryhope. . . .	1,558	1,425	3,129	..	..	76·0	1869
18	Pendleton . . .	1,578	..	3,659	59·7	..	75·0	1869
19	Lower Duffryn. .	1,588	25	1,850	52·0	63·0	78·0	1867
20	Shircoaks . . .	1,590	1,390?	3,750	74·0	61·7	73·5	1869
21	Upper Duffryn. .	1,690	150	2,327	76·0	67·0	74·0	1867
22	Dukinfield . . .	1,809	..	..	47·6	53·5	73·6	1870
23	Bonne Espérance .	1,886	..	..	32·0	49·0	64·4	1867
24	Grand Mambaury.	1,922	..	..	32·0	50·0	72·5	1867
25	Pendleton . . .	2,064	..	3,035	59·7	..	81·0	1869
26	Sacrée Madame .	2,079	..	..	38·3	50·9	71·6	1867
27	Wearmouth . .	2,140	2,039	3,000	40·6	53·0	79·5	1870
28	Poirier	2,203	..	..	32·0	57·2	68·0	1867
29	Thèvson . . .	2,309	..	..	38·3	57·2	71·6	1867
30	Rosebridge. . .	2,418	2,218?	560	41·4	54·9	62·9	1870
31	Sacrée Madame .	2,498	..	..	65·3	68·0	81·5	1867
	EXPERIMENTS received from M. GUIBAL, Mons, April, 1870.							
32	Puits St. Théodore	2,309	..	..	39·6	56·3	72·5	1870
33	„ „	2,496	..	..	33·3	62·1	..	1870
34	Puit Mécanique .	1,391	..	..	50·0	53·6	62·1	1870
35	„ „	2,083	..	..	50·0	53·6	69·8	1870

[1] The bottom of this pit is 390 feet above the level of the sea.

The following experiments were made to find the effect produced by the men, horses, and burning of lights, upon the temperature of the air at the Seaham and Monkwearmouth collieries:—

TABLE XIX.

—	Temperature in Return Air Course at some distance from the Upcast Shaft.	
	Seaham.	Monk-wearmouth.
Colliery at Work .	76°	79½°
„ off Work .	76½	78½
	More ½	Less 1

The curious result given by the Seaham experiment may be partly due to a difference in the temperature at the surface. The experiments at Monkwearmouth were made within twelve hours of each other, and there was no difference worthy of note in the surface temperature.

12. *Neath Colliery, Staffordshire.*

The data respecting the temperature of this colliery and the Cornish mines next referred to were kindly supplied by the Managers of the mines, which have probably the highest temperature in which men work in England.

Date of Experiment, January 15, 1870.

Depth of pit . . . . . 900 feet to thick coal.
Height of seam . . . . . 30 feet.
Temperature at bottom of downcast . . . . . 40°.
„ in workings (ordinary) . . . . . 80°.
„ „ maximum . . . . . 90°.
Quantity of air passing into the mine, 4,000 cubic feet per minute.
Normal temperature of the coal . . . . . 50°.
Hours of labour for men . . . . . 10 hours.

As small a volume of air as possible is allowed to traverse the workings owing to the coal being liable to spontaneous combustion.

13. *Clifford Amalgamated Mine, Cornwall.*

The following are the particulars relating to the temperature of this mine, the great heat of which is due to the streams of hot water issuing from the rock:—

Date of Experiment, December, 1869.

Depth of mine	1,620 feet.
Quantity of air passing into mine	(unknown)
Temperature of water at the bottom of mine	72°.
„ „ issuing from the rock	126°.
„ air in which men work	120°.
Length of time men remain underground	6 hours.
„ „ work consecutively	25 minutes.
„ „ rest between intervals of work	30 „

During the intervals of rest the miners resuscitate themselves by plunging into the water at the bottom of the mine, which has a temperature of 72°. In regard to the effect of this high temperature upon the health of the men, the Manager, through whose kindness the above information is presented, states that they are subject to heart complaint, but do not suffer from consumption and rheumatism, as is the case with the men working in cold mines.

The highest temperature in the Fowey Consols Mine when it was working was 98°, at a depth of 2,082 feet.

4. *Causes of High Temperature in Mines.*

The high temperature of mines is attributable to the following causes:—

1. Heat due to the distance of the bottom of the mine from the surface.
2. Heat due to the increased density of the air.
3. Heat due to the explosion of gunpowder.
4. Heat due to animal life, *i.e.* men and horses.
5. Heat due to the burning of lights.
6. Heat due to friction and percussion in working the mine.
7. Heat due to the chemical decomposition of sulphide ores, such as iron pyrites, etc.
8. Heat due to other unexplained causes.

Chief among the causes of high temperature of deep mines may be mentioned the increase of temperature of the strata due to increased depth.

There still remains doubt as to the value of the various hypotheses which have been advanced to account for this increase in temperature, but whether the centre of the earth is solid, liquid, or gaseous, whether the heat radiating from the sun and the heat radiating from the interior of the globe institute a constant reciprocating action, whether the temperature of the earth increases directly in a regular scale of progression or intermittently, whether subterranean heat is distributed irregularly in certain districts,

whether the thickness of the earth's crust is from 30 miles to 40 miles, or as suggested by Mr. Hopkins 800 miles—are all questions about which uncertainty still prevails, experiments having hitherto failed to effect their elucidation.

Whatever doubts may exist on these points it is an ascertained fact that the temperature of the earth increases with the distance from the surface, and it remains a question as to whether this increase is due to the internal temperature of the globe or to the weight of the overlying strata making sensible an amount of heat which would otherwise be latent.

To what degree the temperature of strata is effected by the difference in density of terrestrial materials is illustrated by the results of Mr. Henwood's experiments given on page 364. These experiments appear to indicate the conductive power of slate, copper ore, rock, tin ore, and granite, to vary respectively in the proportion of 1° increase in temperature in descending every 37, 38, 40, 43, and 51 feet.

As to the difference in the temperature of coal and the rocks adjacent to it, at an equal distance from the surface, the experiments of Von Decken, according to Mr. Henwood, proved the higher temperature of the coal, but their relative temperature would appear from the experiments given in Table XII. to be irregular, since the trials in the Welsh collieries prove the respective temperatures of stone and coal at depths from the surface, varying from 360 feet to 1,690 feet, to be 64° and 63°·4, whilst the observations in the Welsh collieries at the depth of 1,988 feet to 2,214 feet show these temperatures to be 80°·6 and 70°. It is scarcely justifiable to consider this contrary result due to the difference in the distance from the surface.

On an examination of the results shown in Tables III., IV., V., and VI., of a large number of experiments made for the purpose of proving the rate of increase of terrestrial temperature, the following conclusions may be arrived at:—

1. In the Cornish mines (Table III.) the number of feet of depth per degree of increase varies, in distances from 500 feet to 1,500 feet from the surface, from 43 feet to 56 feet, the average being 52·45 feet per degree, and the average from the surface to a depth of 1,500 feet being 52 feet.

2. At Rosebridge (Table IV.), the deepest English coal-mine, the feet per degree varies, in distances from 1,900 feet to 2,400 feet from the surface, from 41 feet to 53·3 feet, from the surface to a depth of 1,900 feet being 53·3 feet, the average being 49·17 feet, and the average from the surface to a depth of 2,400 feet being 55 feet.

3. In the five important series of experiments given in Table IV. the following results are obtained:—

	Depth.	Rate of Increase.
	feet.	feet.
Monkwearmouth	1,600	1° for every 67·4
Dukinfield	2,100	78·2
Rosebridge	2,400	55·0
South Hetton	1,900	40·8
Torcy	2,600	51·4
Average	2,120	58·56
Average of the two deepest .	2,500	53·2

4. The chief deductions derived from Table VI. are as follows:—

TABLE XX.

Number of Observations.	Depth from Surface.		Distance in Feet per Degree of Increase in Temperature.		
	From.	To.	Maximum.	Minimum.	Average.
	feet.	feet.			
7	184	724	58·0	38·2	46·24
11	724	1,690	78·4	42·2	66·62
5	1,690	2,055	78·2	40·8	59·60
4	2,055	2,676	57·0	51·4	54·52

The following is a summary of these abstracts:—

	Distance from Surface.	Feet per Degree.
	feet.	
1. Cornish mines	1,500	52·00
2. Rosebridge Colliery	2,400	53·30
3. Average of five mines . . .	1,600 to 2,000	58·56
4. Average of last two observations in Table XX.	1,690 to 2,676	56·58
Average	..	55·09

As there is insufficient evidence to prove that the ratio of increase is progressive as indicated by the above Table (No. XX.), the Author considers that the above rate of 1° increase in temperature for every 55 feet in depth, taken from a distance of 60 feet below the surface, is as nearly correct as the data afforded by the experiments made will allow.

Some data as to what extent the temperature of the strata is affected by the relative position of the point of observation to the sea level are afforded by Table VI., and are tabulated as follows:—

TABLE XXI.

NAME OF COLLIERY.	Depth of Point of Observation below Surface.	Depth of Point of Observation below Sea Level.	Temperature.	Feet per Degree of Increase in Temperature.
	feet.	feet.	°	
Upper Duffryn	1,210	10 (above)	65·0	76·3
Hucknall	1,250	1,050	70·0	59·5
New Tredegar	1,549	262	69·0	78·4
Monkwearmouth	1,584	1,483	72·6	67·4
Upper Duffryn	1,690	140	75·0	75·0
Puits de Grenelle	1,795	1,676	81·9	60·0

From these results it would appear that the temperature of strata is, in some degree, dependent upon its locality with respect to the sea level to an extent apparently irrespective of the distance from the surface, and amounting to one-fourth more in depth per degree. If therefore the rate of increase of temperature in mines, varying in elevation from 100 to 400 feet above the sea level, be taken at 1° for every 55 feet, the rate for mines situated, like those of South Wales, at a high elevation, will be, for a certain distance, about 1° for every 70 feet.

It may therefore be estimated from the above, taking the unalterable temperature to be 50° at a distance of 60 feet from the surface, that the normal temperature of coal at a depth of 7,000 feet from the surface is 176°.

The manner in which it may be possible to reduce this temperature is discussed under the head of ventilation, but the mode in which the force of this heat will be directed may be here referred to. Heat is transmitted from one body to another in three different ways:

1. By radiation.
2. By conduction.
3. By convection or contact with cold air.

The decrease of the temperature of the passages in mines is only affected by the third of these courses, since radiant heat has the remarkable quality of passing through a moderate thickness of air without suffering appreciable loss or heating the air sensibly, and it may thus be considered that heat cannot be transmitted to air directly by radiation.

The conduction of heat from the strata to the exposed face of the coal or rock is continually going on, but with a constantly diminishing effect; this heat, however, is only carried to the face of the strata, and is taken beyond this point by the third method of cooling, viz., that of 'convection,' which is the conduction of heat, particle by particle, by the contact of a current of air at a lower

temperature than that of the heated body. The quantity of heat thus evolved, and the time taken to cool the body from which the heat is 'convected,' is treated of in a future section.

Another possible cause of increased atmospheric temperature is the increased temperature due to the condensation of the air, this being caused by the development of sensible heat consequent upon the weight or pressure of the atmosphere, which increases in proportion to its depth.

Judging from the decrease in temperature due to rarefaction as observed in ascending from the surface of the earth, the increase in temperature produced by condensation has been estimated to be equal to 1° for every 330 feet of depth.

Humboldt considered his observations proved the increased density of the air to have no effect upon the temperature. The only experiments bearing on this point will be found in Table XVIII.

The following is a comparison between two collieries, the underground workings of which differ in their altitude:—

TABLE XXII.

Colliery.	Depth to point of Observation.		Distance from the Pit to the point of Observation.	Temperature.		
	From Surface.	Below the Sea Level.		At Surface.	At Bottom of Pit.	In Return Air Course.
	feet.	feet.	yards.	°	°	°
Shireoaks	1,590	1,390?	3,750	74	61·7	73·5
Upper Duffryn . .	1,690	150	2,327	76	67·0	74·0

As the difference between these two results seems to be nearly in proportion to the distance of the point of observation from the shaft, any effect due to the difference in the density of the air cannot be traced. The comparison however may be influenced to some extent by the volume of air circulating.

The increase of temperature due to this cause is constantly subject to the resisting force consequent upon the absorption of heat from the strata by the air in descending and traversing a mine, the result of which is expansion.

It will be observed, on referring to Table XVIII., that when the temperature of the air at the top of the pit is higher than about 66°, the temperature in every case is reduced to about 66° in descending, but when the surface air has a lower temperature than this, the temperature increases to a greater or less extent, only exceeding 66° in the case of the Sacrée Madame pit, in which the air increases

2·7 inches in about 2,500 feet, and this will perhaps be the increase due to the agency of the antagonistic forces referred to.

Taking all into account, the actual effect in the temperature of the air due to its condensation may be estimated at about 1° for every 800 feet, and taking the mean average temperature throughout the year at the surface to be 50°, the temperature of the air due to this cause at the bottom of a mine 7,000 feet in depth will be 59°.

The quantity of heat generated by the explosion of gunpowder, the respiration and radiation from the bodies of men and horses, the burning of lights and the friction and percussion which takes place in excavating the coal or stone, cannot be considered to be of much consequence. In the first place, the employment of gunpowder, which has the double objection of being unsafe and inimical to ventilation, is being fast superseded by hydraulic and other wedging tools, about six of which were brought under notice in 1869. In regard to the horses employed for the purpose of leading coals underground, as the progress of mining engineering is gradually resulting in their replacement by machinery, they may be considered to be out of the question; the heat emitted by the men, the combustion consequent upon the lighting of the mine, the friction in hewing, drilling, &c., is a constant quantity, amounting however to very little. It will be seen, on reference to page 369, that whilst at Seaham colliery the temperature of the return air, when the working of the mine was suspended, was 0°·5 higher than when in full operation, at Monkwearmouth it was 1° lower. Dr. Forbes, in a Paper read before the Cornwall Geological Society in 1822, calculated that the total increase of heat due to these causes did not amount to more than 0°·2. They may therefore be considered to have no appreciable influence on the temperature of the air, more especially since they only come into operation, for the most part, in the workings of the mine, when the temperature of the air after it has passed the last workman is of little importance. The amount of heat due to the respiration of a man in one hour is as follows:—

	Units.
Total amount of heat	284
Absorbed by vapour during respiration . . .	93
Actual quantity of heat emitted	191

The spontaneous combustion which occasionally takes place underground at some of the Leicestershire and Staffordshire collieries is generally attributed to the chemical decomposition of sulphide ores, iron pyrites being most frequently met with. As the oxygen of the air promotes this, not only has excessive ventilation to be guarded against, but in Leicestershire the spaces con-

taining the débris, resulting from the working of the coal, have to be protected from the air by walls plastered with clay. At the Neath colliery in Staffordshire, the temperature, owing chiefly to this cause, varies from 80° to 90°. This difficulty, however, which would be difficult to encounter in deep mining, is so very exceptional that it need scarcely be noted.

The remaining cause of the increase of temperature in mines has been designated 'unexplained,' and refers to several cases known to the writer in which the temperature found in the workings has been proved to be beyond the combined effect of the normal temperature of the coal and other known causes. The case most worthy of remark occurred at Monkwearmouth colliery, when, by an experiment made some years ago, the normal temperature of the coal at one part of the workings was found to be 86°, whilst the temperature of the air within a few feet of the same place was 95°; the working of this place was discontinued. In working the longwall system, which is in operation at this colliery, the removal of the coal causes the subsidence of the superincumbent strata, and whether the trituration of the overlying rocks, which may be in continuous motion for a considerable time, evolves heat sufficient to cause the amount mentioned, it is difficult to determine. The consideration of this, like the decomposition of pyrites, need not be entered into.

d. Consideration of the Difficulties of Deep Mining beyond that of Temperature.

1. *Pressure of Superincumbent Strata.*

In comparing the effect of pressure upon the workings of mines between the depths of 200 and 600 yards, there is not actually much difference to be observed, the weight of the roof of the coal often being as difficult to withstand in the shallow as in the deeper pits. The actual dead weight of the strata, which in a mine 7,000 feet deep would amount to about 3·1 tons to the square inch, is of course never actually felt, as the pressure is modified by the relations of one mass to another, the overlying rocks having a reciprocating and self-supporting tendency.

The effect of the pressure of the overlying strata, as observed in Derbyshire, upon the gate-roads of the longwall system of working, may be seen by the sketches on Plate 21. Fig. 7 represents the effect of the pressure within a week of the removal of the coal, and Fig. 8, the position of the strata a few weeks later. It will be seen from the latter sketch that, owing to the upheaval of the floor, the gate-road has actually to be cut afresh in the stone above.

The Rosebridge colliery is not yet sufficiently developed to allow an opinion to be formed as to what will be the effect of pressure at

a depth of 2,400 feet, but, judging from the present workings, a heavy pressure may be apprehended. Almost similar conditions however have been seen by the Author at pits of much less depth. The hardness and height of seams of coal have hitherto been proved to be unaffected by their distance from the surface, and it is probable that the pressure of the superincumbent strata will not be found to be in proportion to its extent. It cannot but be expected, nevertheless, that it will be much more serious in very deep than in shallow mines.

2. *Working the Coal.*

It is impossible, even in mines at ordinary depths, to judge correctly as to the best mode of working the coal, without some knowledge of the various circumstances of roof, floor, &c., which affect the question.

In suggesting a system for working a mine of great depth, the following desiderata are of consequence:

1. As few roads or drifts as possible should be made in order to shorten the distance the air has to travel.
2. As many of the roads should be made permanent as is practicable.
3. The face of coal to be worked should be as compactly situated as is possible.
4. Few, if any, standing blocks or pillars of coal should be allowed to stand.

With these points in view, the Author has ventured to make a skeleton sketch (Fig. 9, Plate 21), showing what appears to be the most profitable mode of working. The area of the tract of coal shown on the plan is taken at two square miles, being equal to a square having the sides about 2,500 yards in length. The tract is divided into four districts, only one of which is to be worked at a time.

The current of fresh air is taken to the face of coal by airways going in the direction from D towards B; at the point B, the current of air splits, and each current, after traversing a face of coal 500 yards in length, returns by passages to the upcast shaft. A face of coal 800 yards in length in Nottingham worked on a system closely allied to this produces 1,000 tons per day, the seam being about 3 feet 6 inches high, and it is estimated that a face 1,000 yards in length will produce the same quantity.

3. *Ventilation.*

Having estimated the temperature from all causes which may be expected in a coal-mine at a depth of 7,000 feet, the question

as to the extent to which ventilation can be made to reduce this temperature may be considered.

It may be desirable in the first place to refer to the effect of ventilation in cooling the strata as evinced by the experiments previously detailed.

The following Table (p. 379) shows the rate of increase of temperature in the air in passing from the bottom of the pit to the workings of several mines.

It will be seen from the above irregular results that the average increase in the temperatures in the airways is about 1°·5 for each 500 yards.

It will also be remarked that the average temperature at the hottest part of the workings is slightly in excess of the average approximate normal temperature of the coal: this is not surprising when it is considered that the present modes of ventilation are only arranged for a limited volume of air, and that when the pillar and stall mode of working is adopted the air travels almost double the distance that it does in some cases of longwall working.

Other instances of the cooling effect of ventilation are as follows:—

At Rosebridge, where the normal temperature of the coal at 2,418 feet is 93½°, the thermometers within an inch of a face of coal (from which two feet had recently been cut, after having been exposed to a current of air less than 2,000 cubic feet per minute for 16 hours) stood at 77°·9, this being the highest of nine readings, taken in the course of 65 minutes. The temperature at a "face," which had stood four weeks exposed to a current of 4,500 cubic feet per minute was 61°·3. Again, at Monkwearmouth, the temperature, near to a face which had stood for 12 weeks exposed to a current (having a temperature of 71°) of 4,000 cubic feet per minute, was 73°·2.

At Seaham colliery the borings at various depths in the coal by the side of an airway, with 65,000 cubic feet per minute passing, proved that whilst the external temperature was 59°·5, the reading two feet from the face was 59°·75, and the distance from the face to the point at which the normal temperature of 74° would be reached was about 13 feet.

The experiments recorded in Table IX. show in a very unaccountable way that the normal temperature of the coal seam from January 1866 to January 1870 has increased from 80°·1 to 84°·7 at the face of the workings. Near the main airway the temperature of the coal 4 feet from the face has been reduced in the same period from 72° to 69°·5.

The fall in temperature at Rosebridge from 93°·5 to 77°·9 in so short a time indicates, along with other cases, the much more rapid loss of heat which takes place at a high temperature, and it

TABLE XXIII.

NAME OF COLLIERY.	Temperature at Bottom of Pit.	Distance from Surface to Point of Observation.	Temperature on Air Way at Various Distances (in yards) from the Shaft.								At Face.		Normal Temperature.
			150	500	1,000	1,500	2,000	2,500	3,000	3,500	Distance from Shaft.	Temperature.	
	°	feet. Approximate.	°	°	°	°	°	°	°	°	yards.	°	Approx. °
Rosebridge	54·9	2,418	64·3	..	..	..	..	..	..	..	..	..	..
Monkwearmouth . . .	53·0	2,200	..	..	..	62·0	70·0	75·0	78·5	..	3,100	83·5	86·0
Seaham	57·7	1,524	..	..	..	59·8	..	64·1	62·9	66·3	4,572	76·0	74·0
Hucknall	42·0	1,200	47 0	..	60·5	..	..	..	..	..	1,000	67·0	70·0
Shireoaks	61·7	1,545	..	..	62·7	67·0	..	..	..	..	2,037	73·3	74·0
Upper Duffryn	67·0	1,400	62·0	..	..	66·0	66·0	..	..	..	1,900	66·0	69·0
New Tredegar	53·0	1,350	..	..	65·0	..	..	..	..	..	1,500	71·5	66·0
Vochriw	59·0	1,000	..	..	59·0	59·0	65·0	..	..	..	2,000	65·0	61·0
	56·0	1,580	56·8	..	61·8	62·8	67·0	68·6	71·2	66·3	2·587	71·7	71·4

Mean increase in temperature upon main air-road 2,587, equal to 1°·47 for each 500 yards.

is natural to suppose that if the above decrease in temperature occurs so quickly the loss of heat from a "coal-face" having a normal temperature of 176° will, comparatively, be even still more rapid.

The following are the dimensions of the airways for the proposed mode of working shown in Fig. 9:—

	Main Intake.				Return to the Right from B.				Return to the Left from B.				Total Area.
	Length.	No.	Dimensions.	Area.	Length.	No.	Dimensions.	Area.	Length.	No.	Dimensions.	Area.	
	yards.		feet.	sq. ft.	yards.		feet.	sq. ft.	yards.		feet.	sq. ft.	sq. ft.
Main Intake .	1,500	2	8×12	192	..	..	..	..	..	..	..	..	192
B to C . . .	..	..	..	..	500	1	9×6	54	..	..	..	..	108
B to A . . .	..	..	..	..	..	..	..	..	500	1	9×6	54	
Return, C to Upcast . . .	..	..	..	..	990	1	8×12	96	..	..	..	..	213
Ditto, A to ditto	..	..	..	..	..	..	..	..	1,990	1	9×13	117	

In considering the amount of ventilation required to overcome the temperature of the mine to such a degree as to admit of men being employed in getting the coal, the following questions must be considered:

1st. The amount of heat which coal and other strata may be expected to give off under conditions which a mine 7,000 feet in depth may be expected to possess, and which have already been described.

2nd. What quantity of air from the surface may be estimated to be requisite to absorb such heat sufficiently to allow the workings of the mine to be prosecuted; and, lastly, what power will be required to produce the necessary amount of ventilation, and in what manner should such power be applied.

In calculating the amount of heat evolved by strata at a depth of 7,000 feet it will be necessary in the first instance to fix upon the temperature which the exposed strata may be supposed to have at different points.

Assuming a mean temperature at the surface of 50°, it has been shown on page 373 that the mean temperature at the bottom of the downcast may be taken at 59°, and from the results of the experiments tabulated on page 379, which show an increase of 1°·5 for every 500 yards along a main airway, the temperature of the intake air at the point P, which is fixed at 65 yards from the face of the coal, will be 62°.

Although a strong current of air passing along an airway having a normal temperature of 176° will afterwards be shown by calculation to be probably very effective in reducing this temperature

quickly, it has been thought, considering the depth, to double the increase in this case, making the temperature of the air at the point P 65°.

The coal from the face 1,000 yards in length may be estimated to be removed at the rate of 130 yards per annum. The temperature of the exposed surface of the strata in the 65 yards from P to B is assumed to have a temperature of 80°.

The size of the road at the face is given as 9 feet by 6 feet, and the time it would take for the face of the coal to be worked from A to B (Fig. 9) would be about seven days, during the whole of which time the surface of the strata would be giving off so many units of heat. Fig. 10 has been made from calculations showing the number of units of heat which would be given off according to the length of time of exposure for each section, and hence the distance at which the normal temperature of 176° may be supposed to exist has been computed.

The average temperature of the airway is arrived at as follows:

Let U be the quantity of heat in units per square foot per hour which is lost by contact with cold air having a temperature 1° lower than the exposed surface, for a passage 6 feet high, according to experiments by Dulong, Peclet, and others; this equals ·421.

T = the temperature at which the air enters at P = 65°.

T_1 = the temperature at which the air enters the return air-road at A and C (Fig. 9); this is taken at 89°, as being the highest temperature at which a man can work for a continuous period.

T_2 = the average temperature of the air from B, to A and C; viz.:

$$\frac{T + T'}{2} = \frac{89° + 65°}{2} = 77°.$$

T_3. The temperature of the exposed coal and stone in the passages from P to C.

K. A figure expressing the ratio of heat lost by contact with cool air, with various differences of temperature, according to the experiments and formulæ of Dulong.

L = units of heat lost per square foot per hour.

Then $L = U \times (T_3 - T_2) \times K$.

The total amount of heat emitted from the exposed heated surface may be calculated as follows:

U	T_3	T_2	K	L	Length of Air Channel. Feet.	Length of Section of Perimeter.	Units of Heat Lost per Hour for each Section.
·421 ×	(176° −	77°) ×	1·40 =	58·35	× 3,000	× 6	= 1,050,300
·421 ×	(145 −	77) ×	1·28 =	36·64	× ,,	× 3	= 329,760
·421 ×	(135 −	77) ×	1·23 =	30·03	× ,,	× 3	= 270,270
·421 ×	(125 −	77) ×	1·21 =	24·45	× ,,	× 3	= 220,050
·421 ×	(120 −	77) ×	1·17 =	21·18	× ,,	× 3	= 190,620
·421 ×	(115 −	77) ×	1·13 =	18·08	× ,,	× 3	= 162,720
·421 ×	(110 −	77) ×	1·08 =	15·00	× ,,	× 9	= 405,000
·421 ×	(80 −	65) ×	0·92 =	5·80	× 195 ×	(40×2)	= 90,480
						Total units of heat given off per hour from P to A and C	2,719,200

$$\frac{2,719,200}{60} = 45,320 \text{ units of heat given off per minute.}$$

The question now is what quantity of air introduced at the point P at a temperature of 65° will be sufficient to absorb the whole of this heat and yet only reach at the points A and C a temperature of 89°.

Let S = specific heat of air at a pressure of 30 inches of mercury = ·238.

I = pressure at the bottom of a pit 7,000 feet deep in atmosphere = 1·292.

S_1 = specific heat of air at a pressure of 1·292 atmosphere.

$$\text{Then } S_1 = S \times \sqrt{1·292} = ·270.$$

W_1 = weight of a cubic foot of air at a depth of 7,000 feet.

W = weight of a cubic foot of air at a temperature of 32° and a pressure of 30 inches of mercury = ·0807.

t = average temperature of air passing from P to A and C

$$= \frac{65 + 89}{2} = 77°.$$

$$\text{Then } W_1 = W \times I \times \frac{493·2}{77° + 461·2} = ·0956.$$

t_1 = amount of heat to be absorbed by air = 89° − 65° = 24°.

U = units of heat required to raise the temperature of 1 cubic foot of air, having weight and specific heat represented by W_1 and S_1, 24°.

Then $U = t_1 \times S_1 \times W_1$, or $24° \times ·270 \times ·0956 = 619$.

It is estimated that 45,320 units will be given off per hour and ·619 units of heat will be required to raise the temperature of 1 cubic foot of air 24°.

Therefore $\frac{45320}{·619}$ = 73,215 cubic feet of air required per minute at the point P, the quantity being split into two equal volumes at B.

It may seem somewhat utopian to suggest this comparatively small quantity of air to reduce the temperature of the mine to the great extent required; but it may be remarked that, in the ordinary working and ventilation of coal-mines, there is seldom a current of more than 5,000 or 8,000 cubic feet per minute passing round the face, and this quantity is frequently allowed to enter the workings at a temperature of nearly 70°.

The calculations relating to the amount of heat given off by the strata are based upon the formulæ of Dulong, which show the loss in units of heat per square foot per hour due to the contact of cold air, under the conditions given, to be ·421.

To prove the accuracy of this term, the following interesting experiment has been undertaken at the request of the Author by Mr. Fowler at the Hucknall colliery, near Nottingham.

The experiment was made shortly after midnight before any workmen were in the pit, at two ends of a face of coal 600 feet in length, and exposing a total superficial area, including parts of the gate roads, *g g g*, of 28,000 square feet.

The volume of air passing along the face was measured by an anemometer, and simultaneously the temperatures at A and B were observed.

The details of the experiment are as follows:—

Current of air passing from A to B in cubic feet . . .	17,000
Normal temperature of coal and adjacent rocks . . .	70°
Average temperature of the exposed surfaces	66°
Temperature of air at point A	58°
,, ,, B	62°
Superficial area of exposed surface in square feet . . .	28,800

At this depth the weight per cubic foot of air will be ·085 lb., and the specific heat of air may be taken at ·24.

The heat absorbed by the air equals $62° - 58° = 4°$.

The difference between the temperature of the exposed mineral and the temperature of air equals $66° - \frac{62 + 58}{2} = 6°$.

Then the units of heat given off by the exposed strata per square foot per hour will be as follows:—

$$\frac{17{,}000 \times (62 - 58) \times \cdot 24 \times \cdot 085 \times 60}{28{,}800 \times \left(66 - \frac{62 + 58}{2}\right)} = \cdot 482.$$

The units of heat emitted, according to the formulæ of Dulong, amount to ·449 per square foot per hour.

Before commencing with the estimate of the power required to produce the ventilation, it may be interesting to show by what

means the line on Fig. 10, indicating the points at which the normal temperature of the mineral may be expected, has been arrived at.

Let c be the conducting power or quantity of heat in units transmitted per square foot per hour by a plate 1 inch thick, where the two surfaces differ 1° in temperature.

For ordinary stone this is 13·68, and for brickwork or baked clay, 4·83.

The average conducting power of coal, and the strata surrounding it, may be taken at 10.

T = normal temperature of coal or stone = 176°.

T_1 = temperature to which any point of the perimeter of the air-road A B C has cooled down.

T_2 = mean temperature of the mineral between the points at which the temperatures T and T_1 exist = $\frac{T_1 + T.}{2}$

T_3 = difference in temperature between T and T_2.

Then $T_3 \times c$ = number of units of heat per square foot per hour which have to be given off by conduction from the point where the temperature T exists, to the "face."

If the number thus resulting be divided by the number of units of heat lost per hour by convection, the number of inches from the surface of the mineral to the point at which the mean temperature T_2 exists will be the result, and this multiplied by two will give the distance from the face at which the normal temperature is found.

Using the figures given on page 382, the following results will be arrived at:—

	Distance from the Surface of the Mineral at which the Normal Temperature is estimated to exist.
$\frac{10 \times \left(176° - \frac{145° + 176°}{2}\right) \times 2}{36 \cdot 64}$	= 9·0 inches.
$\frac{10\left(176° - \frac{135° + 176°}{2}\right) \times 2}{30 \cdot 03}$	= 13·6 „
$\frac{10\left(176° - \frac{125° + 176°}{2}\right) \times 2}{24 \cdot 45}$	= 20·8 „
$\frac{10\left(176° - \frac{120° + 176°}{2}\right) \times 2}{21 \cdot 18}$	= 26·4 „

$$\frac{10\left(176^\circ - \frac{115^\circ + 176^\circ}{2}\right) \times 2}{18{\cdot}08} = 33{\cdot}7 \text{ inches.}$$

$$\frac{10\left(176^\circ - \frac{110^\circ + 176^\circ}{2}\right) \times 2}{15{\cdot}00} = 44{\cdot}0 \quad ,,$$

(Distance from the Surface of the Mineral at which the Normal Temperature is estimated to exist.)

This may be checked by calculating the time it would take to cool at one of the points given.

Taking the point at which the temperature of the face is assumed to be 125°, and the distance from the face to the point at which the temperature reaches 176°, to be 20·8 inches, the time occupied in effecting this loss of heat is reached in the following manner :

Let D = distance in feet from the surface of the mineral to the point at which the normal temperature exists = 1·733.
U = number of units of heat lost by convection per square foot per hour.
l = weight per cubic foot of stone ; taken at 150 lbs.
S = specific heat of rock, shale, etc., near coal-seam ; taken at ·22.
H = number of hours required to lose the mean temperature T_3 in the distance D.

$$\text{Then } H = \frac{D \times l \times S \times T_3}{U} = \frac{1{\cdot}733 \times 150 \times {\cdot}22 \times 25^\circ{\cdot}5}{24{\cdot}45}$$

$$= 59{\cdot}6 \text{ hours.}$$

The actual time which this section of the perimeter is assumed to have been exposed is about three days ; whilst the length of time resulting from the calculation above is just two and a half days ; the error thus being on the right side.

By a similar calculation to the above, it appears that, to reduce the temperature of the mineral forming the sides of the Main air-way (DP) from 176° to a mean of $\frac{59^\circ + 65^\circ}{2}$, by a current of 73,000 cubic feet per minute, entering at a temperature of 59°, a period of only forty days will be required. As this calculation may be interesting, it is given below.

It is supposed that the strata will retain a uniform temperature when the normal temperature exists at a distance of 12 feet from the outer surface.

Let A = total superficial area of the double main-road = 344,400 feet.

d = the distance from the outer surface of the mineral at which the temperature of 176° exists after the cooling is effected = 12 feet.

$C = A \times \frac{d}{2}$ = total cubic feet to be reduced from a temperature 176° to $\frac{59 + 65}{2}$ = 2,066,400 cubic feet.

T = normal temperature of mineral = 176°.

T_1 = average temperature to which it is proposed to reduce the outer surface of the mineral.

Then $C \times l \times S \times (T - T_1)$ = total amount of heat in units to be lost by contact of cool air

$= 2{,}066{,}400 \times 150 \times \cdot 22 \times (176° - 62°) = 7{,}773{,}796{,}800.$

U = units of heat lost by convection per square foot per hour by a passage 8 feet high = ·413.

T_2 = average difference in temperature between the normal temperature and that of the surface of the mineral

$$= \frac{T - T_1}{2} = \frac{176° - 62°}{2} = 57°.$$

Then $U \times T_2 \times A$ = units of heat lost per hour

$= \cdot 413 \times 57° \times 344{,}400 = 8{,}017{,}520$;

and $\frac{7{,}773{,}796{,}800}{8{,}017{,}520} = 958$ hours, or 39·9 days.

In order to facilitate their comprehension, the foregoing simple formulæ have been worked out in each case in figures.

Having now estimated the quantity of heat to be given off by a Mine under certain conditions, and the quantity of air required to reduce this temperature to a defined extent, the third question, as to the power required to produce the amount of ventilation estimated to be necessary, must be considered.

The quantity of 73,000 cubic feet has been estimated to be sufficient to produce the cooling effect required; if to this quantity 37,000 be added for supplying the main-roads, underground engine, and furnace, the total of 110,000 cubic feet per minute may be taken as the total amount of air to be circulated.

The power necessary to produce a certain amount of ventilation can be calculated, if all the conditions of a mine are known, and can also be estimated from the tested results of mines with known conditions. A comparison will be instituted between these methods.

In calculating the power necessary to produce a certain quantity

of air, the following important laws of ventilation must be borne in mind.

The pressure per unit of the sectional area of an air-way required to overcome the friction of air varies:

1. Directly as the length of the air-channel.
2. Directly as the length of the perimeter.
3. Directly as the square of the velocity of the air.
4. Inversely as the sectional area of the air-way.

In the first, second, and fourth laws, the power exerted will increase in the same ratio as the resistances; in the third law the resistance increases as the square of the velocity; and thus, if the velocity be doubled, a quadruple resistance is encountered; but as the quantity is also doubled, the power required to produce such increased quantity will really amount to eight times that required for the original velocity, and will thus be as the cube of the velocity.

To illustrate the action of these laws, the power required to produce ventilation with the two following conditions of air-way may be considered:—

	No. 1.	No. 2.
Area of air passage . .	25 sq. ft.	50 sq. ft.
Perimeter „ „ . .	20 feet.	28·28 feet.
Length „ „ . .	1,000 „	2,000 „
Velocity of air	300 „ per minute.	600 „ per minute.
Pressure required to overcome resistances . .	P.	

It is required to know the proportionate pressure to P necessary to produce the amount of ventilation under the conditions given in case No. 2:

1. The increase of resistance due to the increased length of air-channel will be as 1,000 : 2,000 :: P : 2 P.
2. The increase due to the increased length of the perimeter will be as 20 : 28·28 :: 2 P : 2·828 P.
3. The increase due to the increased velocity of the air-current will be as $300^2 : 600^2 :: 2{\cdot}828\,P : 11{\cdot}312\,P$.
4. Lastly, the decrease due to the increased sectional area of the air-channel will be as 2,000 : 1,000 :: 11·312 P : 5·656 P.

From this it will be seen that the important essentials in arranging air-courses to produce economical ventilation are—

1. That the air-channels should be as short as possible.
2. That they should have as large a sectional area as is practicable.

Having now stated the main principles affecting the pressure required to overcome the resistances, and, consequently, the power

necessary to produce ventilation, it may be well to consider in what way the amount of power necessary to overcome the resistances is arrived at.

A current of air, in passing from the top of a downcast pit through the workings of a mine, and thence to the bottom of the upcast pit, loses the tension due to pressure that is spent in overcoming the friction, and thus the pressure of the air, when it reaches the bottom of the upcast pit, is less than the pressure at the top of the downcast pit, by the amount of pressure absorbed by the friction caused by the various resistances. To ascertain what this loss (which represents the actual power expended in producing a certain amount of ventilation in the workings of a mine) amounts to in the underground passages of a mine, a "water gauge" consisting of a bent glass tube having the form of the letter U, is placed in such a position that the pressure of the air at the bottom of the downcast pit is applied to one leg of the tube, whilst the diminished pressure of the return-air at the bottom of the upcast shaft acts upon the water in the other leg; the difference in the level of water in the tube indicates the pressure in inches of water column required to overcome the sources of resistance in the air-ways.

The weight of 1 square foot of water, 1 inch high, is 5·2 lbs.; and this, multiplied by the difference in water-level in the gauge in inches, will give the pressure in lbs. upon each square foot of air-way; this, multiplied by the number of square feet in area, and by the velocity of the air in feet per minute, gives the total number of ft. lbs. per minute, which, divided by 33,000, gives the H.P. expended in producing the ventilation.

When the power necessary to overcome the resistances of air-ways under any assumed conditions is required to be known, in the absence of the water-gauge it is necessary to use such a formula as will give the friction of each square foot of rubbing-surface past which the air traverses.

Experiments made by Peclet proved this coefficient of friction to be ·000,000,268,81 feet of air-column, of the same density as the air-current, for every square foot of rubbing surface.

The pressure per square foot of section of air-way is found by the following formula:

$$P = \frac{K S V^2}{a} \quad (1).$$

Where P = pressure per square foot.
S = area of rubbing-surface in square feet.
V = velocity of air in feet per minute.
a = square feet of sectional area.
K = coefficient of friction; in this case ·000,000,268,81.

By means of this formula the power necessary to produce the ventilation in the two cases before mentioned may be computed—

1. $\frac{K \times 20000 \times (300)^2}{25} = 19{\cdot}35$ feet of air-column.

2. $\frac{K \times 56560 \times (600)^2}{50} = 109{\cdot}47$ „

The amount of water-column which these equal will be as follows:—

1. $\frac{19{\cdot}35 \times \overset{\text{Weight of a Cubic foot of air.}}{{\cdot}0807}}{5{\cdot}2} = 0{\cdot}289$ inch of water-column.

2. $\frac{109{\cdot}47 \times {\cdot}0807}{5{\cdot}2} = 1{\cdot}699$ „ „

The formula, then, to find the inches of water-column due to any condition of air-way, &c., will be as follows:—

$$\frac{K S V^2 W}{a \times 5{\cdot}2} \quad (2).$$

Where W = weight of a cubic foot of air.

This same formula, expressed as follows, is used by Mr. J. J. Atkinson:—

$$\frac{12 K S (V \times a)^2}{800 a^3} \quad (3);$$

but as this assumes a constant density of air, the former will be used.

At ordinary depths ventilating fans can be worked by a consumption of 6 lbs. of fuel per hour per indicated H.P.; taking 60 per cent. as utilized, this gives 10 lbs. per H.P in the air, which may be taken as a minimum.

The average of observations taken at eleven different collieries gives 59·27 as the percentage of units of heat conserved in the shaft where furnace ventilation is employed, the actual percentage utilized being very much lower than this.

The quantity of fuel consumed per H.P. in the air in five pits in the North of England, varying in depth from 90 yards to 508 yards, ranges from 37 lbs. to 89 lbs. M. Guibal, of Mons, Belgium, calculates that in a 12-feet pit 560 yards deep the furnace would consume 22 lbs., and the mechanical ventilator 11 lbs. per H.P. in the air for a circulation of 53,000 cubic feet per minute, against a total resistance represented by 3·3 inches of water-gauge, and the mean temperature in the upcast shaft being 108° above that in the downcast. The following Table shows the depth at which furnaces

become equal to ventilating machines, assuming that the sources of loss are the same in both cases :—

TABLE XXIV.

Coals consumed by Engine, lbs. per Hour per indicated H.P.	Average Temperature of Air in Upcast Shaft.		
	100°.	150°.	200°.
	Depth in feet.	Depth in feet.	Depth in feet.
8	2,874	3,132	3,390
10	2,298	2,502	2,712
12	1,914	2,088	2,256

It will be understood that at greater depths than those given above the superiority of the furnace ventilation becomes manifest.

For the purpose of calculating, a consumption of 25 lbs. for furnace ventilation, and 14 lbs. per H.P. in the air per hour for mechanical ventilation, may be assumed.

The following formula will then give the total consumption of fuel per twenty-four hours, with any condition of shafts and air-ways :—

$$F = \frac{K S V^2 W Q f 24}{a\, 33000} \quad (4).$$

Where f = consumption of fuel per hour per H.P.

33,000 = No. of lbs. raised 1 foot high in one minute per H.P.

F = Total consumption of fuel in lbs. per twenty-four hours.

Q = Volume of air-current in cubic feet per minute.

Applying this formula to the examples given, the consumption of fuel will be as follows :

$$\frac{\{K S V^2 = 1935\} \times \cdot 0807 \times 14 \times 24 \times 7500}{a \times 33000} = 119 \cdot 24.$$

$$\frac{\{K S V^2 = 109 \cdot 47\} \times \cdot 0807 \times 14 \times 24 \times 30000}{a \times 33000} = 2698 \cdot 46.$$

And the comparative power required for the two conditions of ventilation as given on p. 388 is found thus :

As 119·24 : 2698·46 : : 1 : 22·63.

This result illustrates the law stated in page 387, as to the power requisite to produce ventilation varying as the cube of the velocity of the air-current.

Having now enumerated these general laws of ventilation, their application to the case of a pit 7,000 feet deep may be noticed.

The following are the chief data on which the calculations must be based. It will be observed that 40,000 cubic feet per minute are assumed to pass round each half of the working face, the calculated quantity being 36,500 feet.

TABLE XXV.

Description of Air Channel.	Number.	Reference to Plan (Fig. 9).	Quantity of Air in Cubic Feet per Minute.	Air Channel.					Velocity in Feet per Minute.
				Length in Feet.	Dimensions of Air Channel.	Area Square Feet.	Perimeter in Feet.	Total Rubbing Surface.	
					ft. diam.			sq. ft.	
Downcast pit .	1	..	110,000	7,000	19	283	60	420,000	388
Main airway .	2	D B	50,000	4,500	8×12	96	40	180,000	521
„ „ .	3	D B	50,000	4,500	8×12	96	40	180,000	521
Working face .	4	B A	40,000	1,500	6×9	54	30	45,000	741
„ „ .	5	B C	40,000	1,500	6×9	54	33	45,000	741
Return air course	6	A U	60,000	5,190	9×13	117	44	228,360	513
„ „ „ .	7	C U	52,000	2,990	8×12	96	40	119,600	625
					ft. diam.				
Upcast pit . .	8	..	110,000	7,000	21	346	66	462,000	405

By the formula (2) the following results will be calculated from the above:

		Inches of Water Gauge.	Cubic feet of Air per Minute.	Work done in Feet. lbs. per Minute.
(1)	$\frac{K \times 420{,}000 \times (388)^2 \times \cdot088}{283 \times 5{\cdot}2}$	$= 1{\cdot}02 \times 5{\cdot}2 \times$	110,000 =	583,440
(2 & 3)	$\frac{K \times 360{,}000 \times (521)^2 \times \cdot098}{96 \times 5{\cdot}2}$	$= 5{\cdot}16 \times 5{\cdot}2 \times$	50,000 =	1,341,600
(4 & 5)	$\frac{K \times 90{,}000 \times (741)^2 \times \cdot096}{54 \times 5{\cdot}2}$	$= 4{\cdot}54 \times 5{\cdot}2 \times$	40,000 =	945,424
(6)	$\frac{K \times 228{,}360 \times (513)^2 \times \cdot093}{117 \times 5{\cdot}2}$	$= 1{\cdot}51 \times 5{\cdot}2 \times$	60,000 =	471,120
(7)	$\frac{K \times 119{,}600 \times (625)^2 \times \cdot093}{96 \times 5{\cdot}2}$	$= 2{\cdot}34 \times 5{\cdot}2 \times$	52,000 =	633·736
(8)	$\frac{K \times 462{,}000 \times (405)^2 \times \cdot083}{346 \times 5{\cdot}2}$	$= 0{\cdot}94 \times 5{\cdot}2 \times$	110,000 =	684,320
		15·51		4,659,640

The total H.P., therefore, necessary to produce a ventilation

of 110,000 cubic feet per minute under the conditions stated will be

$$\frac{4659640}{33000} = 141 \text{ H.P.}$$

The water-gauge indicating the resistance due to the friction in the downcast shaft may also be calculated from the data afforded by the observations at Seaham colliery, which are as follows:

		7,000 feet Pit compared.
Quantity of air, cubic feet per minute . . .	193,000	110,000
Area of shaft 154 square feet; available . .	146 sq. ft.	283
Velocity of air, feet per minute	1,322	388
Depth of shaft in feet	1,524	7,000
Length of perimeter of shaft	44	60 (Calculated)
Water-gauge due to friction of downcast pit .	1·4 in.	1·02 in.

The timber in this pit doubtless causes extra friction. For a shaft more free from such causes of friction 1·1 inch of water-gauge may be estimated as the pressure.

The 'water-gauge,' or inches of water-column, due to the resistances in a shaft 7,000 feet deep is arrived at as follows:

The decreased resistance due to the decreased velocity in the deeper pit will be

$$\text{As } (1{,}319)^2 : (388)^2 :: 1{\cdot}1 : {\cdot}095.$$

The increase due to the increased length of the perimeter will be

$$\text{As } 44 : 60 :: {\cdot}095 : {\cdot}13.$$

The increase due to the increased depth of the pit will be

$$\text{As } 1{,}524 : 7{,}000 :: {\cdot}13 : {\cdot}60.$$

And the increase due to the increased sectional area of the shaft will be

$$\text{As } 146 : 283 :: {\cdot}60 : 1{\cdot}16 \text{ inch of water-gauge.}$$

It will be noticed that the result of this calculation, which is based upon actual observation, is slightly in excess of the amount of water-gauge arrived at on p. 391.

The total H.P. required being taken at 141, the next question is, what temperature of the upcast will be required to produce this power in case of furnace ventilation being employed.

The motive column of air, *i.e.*, the difference in weight between the downcast and upcast columns is found by the following formula:

$$M = \frac{h(T - t)}{459 + T}$$

Where M = motive column of air in feet.
T = temperature of upcast.
t = temperature of downcast $\frac{59 + 50}{2} = 54°{\cdot}5$.
h = depth of pit in feet = 7,000 feet.

Putting this in figures, we have

$$M = \frac{7000\,(T - 54°{\cdot}5)}{459 + T}$$

The weight per cubic foot of the column of air forming the motive column will be

$$\frac{1{\cdot}3253 \times 34{\cdot}5}{459 + 54°{\cdot}5} = {\cdot}089 \text{ lb.}$$

Where 1·3253 = weight of 459 cubic feet of air at zero under a pressure of 1 inch of mercury.
34·5 = the mean barometric pressure in the pit.

Then M × ·089 = total weight of 1 foot of area of such motive column in lbs. = W

$$W \times \underset{\text{Air per Minute.}}{\overset{\text{Cubic Feet of}}{110000}} = 141 \text{ H.P.} \therefore W = \frac{141 \times 33000}{110000} = 42{\cdot}3$$

$$\frac{42{\cdot}3}{{\cdot}089} = 475{\cdot}3 = M.$$

Then $M = \frac{7000\,(T - 54°{\cdot}5)}{459 + T} = 475{\cdot}3 \therefore T = 91°{\cdot}9.$

It thus appears that, taking the mean temperature of the downcast pit at 54°·5, a temperature of 91°·9 of the column of air in the upcast shaft will be necessary to produce an effect equal to the expenditure of 141 H.P., which is the power necessary to produce a current of air of 110,000 cubic feet per minute. The question now arises as to what will have to be the temperature at the bottom of the upcast pit to produce a mean temperature of 91°·9.

Fig. 11, Plate 21, has been carefully constructed from observations taken at six upcast pits.

It indicates that the approximate rate at which an air current heated by the furnace cools at distances from 1 to 8,000 feet from the bottom of the upcast pit varies from 77° to 0°·65 per 100 feet of ascension.

The limit to the temperature is placed at 559° (supposing the average outside temperature to be 50°), since this temperature has been proved to be the highest at which a useful effect can be produced by a heated air current, owing to the diminution in the

total weight of the air consequent upon its expansion in volume, being so far counteracted by the friction resulting from the increased velocity, also owing to expansion, as to cause a surplus resistance.

Estimating the loss of temperature after the temperature of the air has decreased to 80° to be uniformly 0°·5 for each 100 feet, the temperature at which the air must enter the bottom of an upcast pit having a depth of 7,000 feet to produce a mean temperature of 91°·9 will be about 141°.

The final question as to the extent to which the heat of the return air current will promote this temperature, and to what degree it will have to be produced by the combustion of fuel, is difficult to determine, since the alteration of the temperature of the air from its leaving the workings to its arrival at the bottom of the upcast pit is uncertain. The observations recorded regarding the temperature of the return air appear to show that, whilst in comparatively shallow pits it is higher than the normal temperature of the coal, at considerable depths it is about the same; but since the depth and temperature under consideration are so much greater than ordinary, it may be assumed that the temperature of 89° which the air has on leaving the working face will be considerably increased in its passage through the permanent return air course to the pit, but to what extent it is difficult to conjecture. Supposing, however, that the temperature of the return air is increased to 100° on its arrival at the furnace, and that this effect will be reduced to 96° by the admixture of fresh air supplied to the furnace, an amount of fuel will be required to heat 140,000 cubic feet of air per minute, having a temperature of 96°. to a temperature of 141°.

The maximum number of units of heat produced by the combustion of 1 lb. of fuel amounts to 13,000, but estimating not more than 4,000 to be available, and taking the weight of 140,000 cubic feet of air at 13,118 lbs.—

$$\frac{12922 \times \overset{\text{Specific Heat of Air.}}{\cdot 263} \times (141 - 96) \times 60 \times 24}{4000} = 55{,}305 \text{ lbs.},$$

or 24·69 tons of coal in 24 hours, being equal to a consumption of 16·34 lbs. of coal per horse-power per hour.

This amount of fuel, from which no deduction is made for the fuel consumed by the boilers attached to the underground engine, exceeds to a small degree the ordinary consumption at collieries of considerable depth, and the result of the above calculation clearly shows the importance of limiting the length and enlarging the area of air channels.

By means of the formulæ given, calculations can readily be made

to find the quantity of air required to ventilate a mine under nearly any conditions, and hence the amount of fuel necessary to produce such ventilation. It will be remarked that, subject to the chief law of ventilation, if the quantity of air should possibly require to be doubled, the fuel necessary to be consumed will amount to eight times the quantity required for the production of a current of 110,000 cubic feet, and this plainly indicates the further economy attained by using, if possible, a comparatively small volume of air for underground ventilation.

Raising the Coal.

The greatest depth from which coal is raised in England is at Dukinfield, where one engine raises the coal from a depth of 2,059 feet. In Belgium coal is raised from much greater depths, and there hemp ropes, frequently upwards of 12 inches broad, are employed. The adoption of tapered ropes, which have been in use to a small extent for some years, will doubtless be found advantageous; but even with ropes of this class, the weight of the rope at depths exceeding 900 yards will probably be so great, and will necessitate the employment of such massive and expensive machinery, that it will probably be desirable at depths beyond this to erect winding engines in intermediate positions between the top and bottom of the pit, and raise the coal at two or more lifts.

Cost of Sinking.

As before observed, the cost of sinking deep mines at present amounts to about $\frac{1}{10}$th of the total cost of the plant; this proportion to the total cost, however, will probably increase, but not to a serious extent. Collieries of great depths will probably have pits of larger diameter than the size at present adopted; this being desirable in order to enable all the coal to be raised at one pit, and thus leave the upcast shaft free for ventilating. On reference to the effect of the cage running in the upcast shaft at Pendleton, as shown on page 363, the advisability of this being observed will be obvious.

6. *Increased Cost of Production.*

The cost of producing coals must necessarily increase with the depth, for the reasons stated on page 351, and the price of coal will probably be proportionately augmented.

The amount of such increase is a question to which it would be unsafe to hazard a reply, owing to the uncertainty of the price of labour, materials, &c., in the future. In regard to the underground charges, the displacement of horses by that class of machinery which will draw the coals from the workings to the pit with the

least possible amount of labour must be regarded as a *sine quâ non*, since the branch roads leading to the workings will only receive a comparatively small amount of ventilation.

The employment of coal-cutting machinery has received very little encouragement since its introduction about fifteen years ago. Numerous patents have been taken out for this class of machinery, the motive power being either hydraulic or an application of compressed air. The machines are most suitable to extremely hard seams, and it is only in this class of work that they have hitherto been found to work economically.

Where adopted, however, they effect a complete saving of hard manual labour, and in this respect they may be found very useful in deep mining. The expansion during exhaustion at the machine of the compressed air is effected at about 32°, but the quantity of air is so very small, that this has but a slight local effect upon the temperature.

7. *Explosive Gas.*

8. *Health of Miners.*

The presence of explosive gas can scarcely be anticipated as a difficulty, since its existence has usually been found to be quite independent of depth. If any fissures exist in the strata overlying a deep seam the tendency will be for the gas to escape.

As the temperature at which it is anticipated deep mines can be worked is little beyond that which now prevails in some deep mines, no deleterious influence can be expected to be exerted on the health of the miners.

The communication is accompanied by a series of drawings, from which Plate 21 has been compiled.

Summary.

The following is a summary of the chief conclusions bearing on the question of Coal Mining in Deep Workings which have been arrived at in the foregoing Paper.

Judging from the statistics of the past few years, the production of the British coal-fields cannot be considered to increase annually in a constantly increasing ratio, as has been surmised, but may be estimated at an average 'output' of 110 millions of tons yearly. Estimating the coal remaining in the British Islands to a depth of 4,000 feet to be 37,300 millions of tons, this quantity of coal will supply the annual demand of 110 millions for three hundred and thirty-nine years; and, taking the limit to deep mining to be a depth

from the surface of 7,000 feet, the further quantity of coal estimated to be workable to this depth is 57,222 millions of tons, which would extend the supply to a period of five hundred and twenty years. The chief localities in the British Islands where coal will probably be found at greater depths than have hitherto been reached were (1) the west coast of Ayrshire, (2) the west of Lancashire, (3) the east of Yorkshire, Derbyshire, Nottinghamshire, and Staffordshire, and (4) below the seams worked at present in the South Wales basin.

Deep mining has been carried on much more extensively in Belgium than in England, there being only twelve pits of a greater depth than 1,500 feet in the latter country, as compared with sixty-eight in the former. The deepest coal mine in the world is probably that of Simon Lambert, in Belgium, which has attained the great depth of 3,489 feet. The deepest coal mine in England is the Rosebridge Colliery, in Lancashire, which has reached a depth of 2,418 feet, the temperature of the coal at that depth being 93°·5.

The distance from the surface of the ground to the stratum of invariable temperature may be taken at 60 feet, and the constant temperature at that depth at 50°. The accounts published between 1809 and 1840 of several hundred experiments, relating to the temperature of coal and metalliferous mines, show the increase of temperature to vary from 1° for every 45 feet, to 1° for every 69 feet; the distance from the surface at which the experiments were made varying from 100 feet to 1,700 feet (Table III.). More recent experiments in England and on the continent are irregular, and show an increase varying from 1° for every 41 feet to 78 feet, the distances from the surface being from 700 feet to 2,600 feet (Table IV.). On comparing the experiments made at the two deepest English coal mines, viz., Rosebridge and Dukinfield, it is found that the increase of temperature due to depth is much less rapid at the latter colliery than at the former; and this difference is assumed, in a Paper read recently by Mr. Hull, to be owing to an amount of heat being lost at Dukinfield from the heavy inclination of the strata, which amounts to about 1 in 3, whilst at Rosebridge the coal seam is nearly level (Table V.). The relation of the position of the bottom of a mine to the sea level influences the temperature, as shown in Tables VI. and XXI. In the latter Table the average increase of the temperature of three mines of a high elevation is 1° for every 71·6 feet, whilst the increase for three mines at some distance below the level of the sea is 1° for every 62·3 feet.

The experiments relating to the underground temperature of the air at Rosebridge Colliery show an increased temperature of the air in passing from the downcast to the upcast shaft of from 55°

to 63°; the air passing through workings the temperature of which was 78°, and the normal temperature of the coal being 93°·5. The experiments at Monkwearmouth (Table VIII.) show the effect of a large volume of air in preventing a rise in temperature. At a distance of 1,800 yards from the shaft, with 80,000 cubic feet of air passing per minute, the temperature was 55°, whilst at a distance of 2,600 yards from the shaft, with 10,000 cubic feet circulating per minute, the temperature was found to be 67°.

The normal temperature of the coal may be estimated, from the results of experiments at Seaham Colliery, to exist in a main air channel, which had been exposed to the air for some time, at a distance of about 13 feet from the surface of the mineral. The highest temperature at which coal mines are worked is probably in Staffordshire, and at Monkwearmouth Colliery, where mines are worked at temperatures varying from 80° to 85°. In Cornwall the workings in the Clifford Tin Mine are prosecuted at a temperature of 120°, in which the miners can only work for twenty-five minutes consecutively, this high temperature being due to the heat of the water issuing from the rock.

It would appear from the contradictory results of the experiments relating to the loss of temperature by different minerals, that no rule can be laid down. It is probable, however, that the temperature of mines is affected to some degree by the varying conducting power of different minerals. In regard to the increase of temperature with the distance from the surface, a careful comparison of all the experiments quoted, and especially of those taken at a greater depth than 2,000 feet, lead to the conclusion that as far as can be judged from experiments already made, the increase of temperature will be 1° for every 55 feet in depth, from the stratum of invariable temperature. The data afforded by the experiments are so irregular, that no law can be established, as to the ratio of increased temperature augmenting or decreasing with increased distance from the surface; though the experiments at South Hetton and at Mouillelonge, as recorded in the Paper, appear to indicate that the rise in temperature becomes more rapid as the distance from the surface increases. Adopting the rate of increase in temperature to be as previously estimated, the normal temperature of a mine 7,000 feet deep will be 176°. Of the three modes by which heat is lost by one substance and absorbed by another, viz., radiation, conduction, and convection, the only influence likely to come into action in a well-ventilated mine of the depth stated will be that of convection. From the observations recorded it would seem that, as a rule, when the temperature at the surface exceeds 66°, the temperature at the bottom of the pit is less than at the top; but when less than 66° at the top of the pit, an increased

temperature is found at the bottom. The increase in the temperature, due to the increased density of the air in deep mines, is estimated at 1° for every 800 feet, making the mean temperature of a pit 7,000 feet deep about 59°. The effect of the heat emitted by workmen, candles, explosion of gunpowder, &c., is estimated not to have any appreciable influence on the temperature of the air circulating in the mine. The experiment at Seaham showed the temperature of the return air to be 0°·5 lower when the mine was in full operation than when the pit was off work, and when no lamps, workmen, &c., were in the workings. An unexplained cause of high temperature had been observed at several collieries, but more particularly at Monkwearmouth, where the temperature of the air on one occasion was found to be 95°, or upwards of 10° higher than the normal temperature of the mineral.

The question, as to the effect of pressure upon deep workings, is unquestionably of great importance, and necessarily very speculative. The mode of working coal, suggested for a depth of 7,000 feet, is arranged as far as possible in accordance with the principle, that the coal should be removed so as to present long lines of fracture, and should be so worked as to cause the superincumbent weight of the strata overlying the 'goaf,' or space where the coal is worked out, to have all its pressure upon such 'goaf,' and a minimum pressure upon the coal.

The increase in temperature in an underground intake air channel appears, from Table XXIII., to average about 1°·5 for every 500 yards.

The question of ventilating a mine 7,000 feet deep, to an extent sufficient to absorb the heat emitted by strata having a normal assumed temperature of 176°, is one of the most important in the inquiry, and the general results arrived at may be thus enumerated:—A. The temperature of the air is estimated to increase from 59°, at the bottom of the downcast pit, to 65° at the point where it reaches the workings.—B. The length of time which would be occupied in cooling the main air-way to such an extent that the sides of the road would have an average temperature of 62°, and the normal temperature would be found as far as 12 feet from the surface of the mineral, is calculated to be forty days.—C. The total number of units of heat emitted by the strata per minute is found by calculation to be 45,320.—D. The volume of air introduced at a temperature of 65°, and assumed to leave the workings at a temperature of 89°, necessary to carry away this number of units of heat, is calculated to be 73,000 cubic feet per minute.—E. Then, taking the total quantity of air necessary for the ventilation of the pit to be 110,000 cubic

feet per minute, the power required to produce this quantity will be 141 H.P., which represents an average temperature in the upcast pit of 92°, for the attainment of which mean temperature a temperature of 141° is required at the bottom of the upcast pit.—F. The quantity of fuel necessary to raise the temperature of the return air from 96° to 141° is found to be 24·69 tons every twenty-four hours.

The laws upon which the amount of power necessary to produce a certain quantity of air under any conditions depend are as follows:—The pressure per unit of sectional area of an air-way, required to overcome the friction of air, varies directly as the length of the air channel, as the length of the perimeter, and as the square of the velocity of the air, and inversely as the sectional area of the air-way. The action of these laws has been demonstrated in the several examples given, where it is shown that the power required to overcome the resistances varies as the cube of the velocity. In drawing a comparison between furnace and mechanical ventilation, it is calculated that, at a depth of about 28,500 feet, the two modes of ventilating become equal, while below this depth the furnace becomes the more effective power.

In the course of this Paper formulæ have been given by means of which the following data may be arrived at.

1. The quantity of heat given off by the workings of a mine, whatever may be the temperature.

2. The quantity of air, introduced at a certain temperature, necessary to absorb the heat given off by the strata, to such an extent, as to increase the temperature of the volume of air to any desired degree.

3. The mode of calculating, from actual observation, the number of units of heat given off per square foot per hour by the strata in any working mine.

4. The distance from the exposed face of a mine at which the normal temperature of the mineral exists, after being exposed to a certain volume of air for any length of time.

5. The time required for the main or other air-roads of a mine, having a known normal temperature, to be permanently cooled down to a certain reduced temperature.

6. The pressure in feet of air and water-column required to cause a certain volume of air to circulate in a mine having certain assumed conditions.

7. The difference in weight between the columns of air in a down-cast and up-cast pit of any depth, where the average temperature of the air in each pit is known.

8. The quantity of fuel required to be consumed, in furnace or mechanical ventilation, to produce a certain volume of air under certain known conditions.

9. The quantity of fuel required to impart any required temperature to a certain volume of air at the bottom of an up-cast pit.

10. From Fig. 11, the average temperature of an up-cast shaft of any depth less than 8,000 feet, having a known temperature at the bottom, may be approximately estimated.

In regard to raising the coal, the probable limit from which coals may be drawn at one lift is estimated to be about 900 yards, below which depth one winding engine at the surface and one in the shaft will be required. An increase in the cost of sinking to great depths, and in the cost of producing the coal, must necessarily be expected; but since the selling price of coal will to a great extent be adjusted accordingly, this can scarcely be considered as a difficulty of much consequence. The employment of machinery will probably be found beneficial in cutting and breaking down coal in deep mines having a high temperature. Some of the coal-cutting machines now at work are driven by compressed air, and the sudden decrease in temperature which compressed air undergoes on exhaustion has been thought likely to be of use in reducing the temperature of a mine. In reality, however, no such reduction can be anticipated, since the quantity of air emitted by the machine bears so very small a proportion to an ordinary current of air, that the effect on the temperature is only to be observed locally, and to a very slight degree.

Finally, it may be stated, that the question of working coal at greater depths than have hitherto been attained, cannot be considered to be one which presents difficulties of any importance, nor is it one which really requires immediate consideration. The Author has endeavoured to prove that coal can be worked at a depth of 7,000 feet, but it will probably be centuries before such a sinking will actually be required; and improvements in the various descriptions of mining machinery, especially such as are intended to facilitate the 'getting' of coal, will probably, before long, render mining to such a depth as practicable as the working of the deep mines of the present day. Commercially, as has been observed, the question will adjust itself to the requirements and the expenditure of the times.

APPENDIX.

To avoid the inconvenience of referring to different authors, it has been thought desirable to append a list of some of the books consulted by the Author in the preparation of the Paper on Deep Mining.

On Heat.—*Box.*
Edinburgh Philosophical Journal.
Mining Institute, Transactions of the North of England.
Reports of the British Association.
On Phenomena.—*Hutchison.*
On the Working of Coal Mines.—*Lambert.*
On Warming Buildings.—*Hood.*
Quarterly Journal of Science.
Lardner's Museum of Science.
Applied Mechanics.—*Rankine.*
Ganot's Physics.—*Atkinson.*
Journal of the Geological Society of London.
The Coal Fields of Great Britain.—*Hull.*
Rules and Tables.—*Rankine.*
Mine Engineering.—*Greenwell.*
Underground Life.—*Simonin.*
Dictionary of Chemistry.—*Watt.*
Philosophical Magazine.
Traité de la Chaleur.—*Peclet.*
Cosmos.—*Humboldt.*
Philosophical Transactions.
English Cyclopædia.
Exploitation des Mines.—*Combes.*

No. 1.

The Author is indebted to M. Gille, of Mons, Belgium, for the following results of observations, which were specially undertaken for the purpose of showing the increase in temperature of air-currents, with distance from the shafts, at several Belgian pits. All the observations recorded have been recently made.

Name of Colliery.	No. of Observation.	Depth of Pit in Feet.	Point of Observation.	Distance from Bottom of Pit to Point of Observation.	Cubic Feet of Air per Minute passing point of Observation.	Temperature in Degrees Fahrenheit.	No. of Men Employed.	Tons of Coal raised per Day
				feet.		°		
Mariemont	1	1,561	Intake	328	4,032	66·2	505	476
,,	2	,,	,,	394	6,850	66·2	,,	,,
,,	3	,,	,,	5,643	1,250	68·0	,,	,,
,,	4	,,	,,	10,958	6,938	68·0	,,	,,
,,	5	,,	Return	5,610	..	72·5	,,	,,
,,	6	,,	,,	10,138	306	73·4	,,	,,
Mariemont	7	1,561	Intake	328	4,618	62·6	490	490
,,	8	,,	,,	394	4,870	62·6	,,	,,
,,	9	,,	,,	1,509	..	68·9	,,	,,
,,	10	,,	Return	2,461	1,507	71·6	,,	,,
,,	11	,,	,,	492	..	73·4	,,	,,
Mariemont	12	1,561	Return	11,434	12,708	71·6	496	490
,,	13	,,	Intake	4,626	5,784	68·45	,,	,,
,,	14	,,	,,	12,271	16,493	68·45	,,	,,
,,	15	,,	Return	427	..	71·6	,,	,,
Bonsecoup	16	1,370	Intake	920	10,989	55·4	524	506
,,	17	,,	,,	2,036	2,392	62·6	,,	,,
,,	18	,,	,,	2,594	3,009	68·0	,,	,,
,,	19	,,	,,	2,200	6,953	62·6	,,	,,
,,	20	,,	,,	2,463	4,314	63·5	,,	,,
,,	21	,,	,,	3,316	1,687	66·2	,,	,,
,,	22	,,	Return	7,322	1,488	71·6	,,	,,
Bonsecoup	23	1,370	Return	8,832	4,506	69·8	524	506
,,	24	,,	,,	10,125	4,607	69·0	,,	,,
,,	25	,,	,,	12,336	6,332	71·6	,,	,,
,,	26	,,	,,	14,304	3,166	74·3	,,	,,
Bonsecoup	27	1,370	Intake	6,494	6,514	66·2	527	563
,,	28	,,	,,	8,430	715	68·0	,,	,,
,,	29	,,	,,	8,800	1,947	68·0	,,	,,
,,	30	,,	,,	9,151	2,907	68·0	,,	,,
,,	31	,,	,,	9,873	4,863	68·0	,,	,,
,,	32	,,	,,	10,365	8,319	66·2	,,	,,
,,	33	,,	Return	10,463	6,838	69·8	,,	,,
,,	34	,,	,,	12,300	1,233	66·2	,,	,,
,,	35	,,	,,	12,956	3,573	71·6	,,	,,
,,	36	,,	,,	12,924	16,253	71·6	,,	,,

No. 2.

Observations made at No. 2 Pit, Charbonnage de l'Agrappe, by M. Delsaur, Mining Engineer.

No. of Observation.	Depth from Surface.	Point of Observation.	Distance from Bottom of Pit.	Cubic Feet of Air per Minute passing point of Observation.	Temperature. Degrees Fahrenheit.			No. of Men, Horses, and Lamps passed over by the Air before reaching point of Observation.		
					Air at Surface.	Air at point of Observation.	Adjacent Rock.	Men.	Horses	Lamps.
	Feet.		Feet.		°	°	°			
1	..	Ladder pit .	..	4,026	58·1	58·1	..	..	..	..
2	679	Winding pit .	..	33,641	59·0	61·7	..	..	..	..
3	,,	At face of coal	3,608	21,139	59·0	63·5	65·75	165	5	173
4	1,014	At face of coal	3,087	4,801	60·35	67·1	68·9	169	5	170
5	,,	Bore-hole .	3,280	12,462	60·35	65·3	..	165	3	117
6	,,	No. 1 Return	2,160	10,489	59·9	64·5	68·9	119	5	124
7	,,	,,	1,919	..	..	66·2	..	119	5	124
8	1,141	South intake .	197	8,925	59·9	59·9	59·9	8	..	9
9	,,	North intake.	295	6,344	59·9	54·5	59·0	10	..	11
10	,,	No. 1 Return	1,394	11,184	59·9	63·5	66·2	109	12	114
11	,,	No. 2 Return	2,362	..	..	64·5	..	40	2	48
12	1,325	No. 1 Intake .	328	8,537	59·0	57·2	58·55	10	..	11
13	,,	No. 2 Intake .	197	18,935	59·0	54·5	57·2	10	..	11
14	,,	North intake.	295	2,352	58·1	61·7	62·6	4	..	5

The temperature of the rock was taken in holes 39 inches deep. 270 tons of coal per day are raised at this pit.

COAL MINING IN DEEP WORKINGS.

Fig 1

PLAN SHEWING "LONG WALL SYSTEM OF WORKING"

Fig 2

PLAN SHEWING PILLAR & STALL SYSTEM OF WORKING

Fig 3

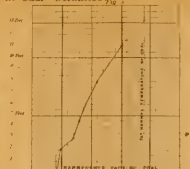


DIAGRAM SHEWING THE INCREASE OF TEMPERATURE IN THE DEEP WORKINGS OF A PILLAR OF COAL WHICH HAS BEEN EXPOSED TWO YEARS TO THE CURRENT OF AIR

Fig 4

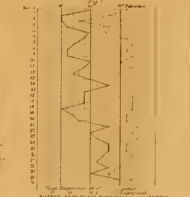


DIAGRAM SHEWING THE RELATIVE TEMPERATURE OF THE STRATA AT DIFFERENT DEPTHS FROM THE SURFACE

Fig 5

SECTIONS SHEWING EFFECT OF PRESSURE UPON TIMBERING IN THE WORKING OF THE PRESENT LONG WALL SYSTEM

Fig 6

PLAN OF PROPOSED MODE OF WORKING COAL AT GREAT DEPTH BY AN ADAPTATION OF THE LONG WALL SYSTEM

Fig 7

DIAGRAM SHEWING THE RELATIVE TEMPERATURE CALCULATED FOR EVERY 50 YARDS OF DEPTH, AND ALSO THE WORKING FACE OF COAL

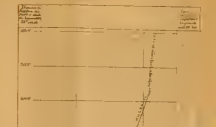


DIAGRAM SHEWING THE RATE AT WHICH A HEATED AIR CURRENT IS COOLED IN ASCENDING AN UPCAST SHAFT FROM OBSERVATIONS IN SHAFTS THE TEMPERATURE OF WHICH VARIED FROM 64° TO 80°

Mr. STEPHENSON said, in his own collieries it had never been attempted to work at such a depth as 7,000 feet. He believed there was scarcely a coal-mine in existence which could not be worked efficiently without the safety-lamp. Most of the great explosions were caused by the collection of gas in the old workings, or "the waste," as it was called in the coal districts. When a sudden depression of the upper strata occurred, this gas was squeezed into the air-courses, so that no practicable amount of ventilation would obviate the danger of explosion. It sometimes happened that years elapsed before this depression took place, and the fact of its not showing itself for so long a period made those in charge less observant, while if it appeared suddenly there was no dealing with it. For three years of his life, it had been his duty to go down a pit at 4 o'clock in the morning, and to visit every working in the mine. In those days ventilation was not so well understood, nor was so much attention paid to barometrical variations as indicating the state of the ventilation; but he believed if the barometer was carefully watched, by those in charge of the pits, many explosions might be prevented. The old-fashioned way was, when gas was met with in the working stalls, to put up a board with the word "Jackets" written upon it, to intimate that the place was unsafe, and if only a small quantity of gas was present, the men drove it out with their jackets.

With regard to safety-lamps, it might be thought that he had a prejudice in favour of George Stephenson's lamp, which competed with that of Sir Humphry Davy; but he had nothing to gain by advocating either one or the other, although he certainly preferred the Geordie lamp to the Davy. He had had a Davy lamp 'fire' in his hand as often as he held it up to the roof of the working, and by constant repetition of this action, the wires would have become red-hot and would even have burst. With a Geordie lamp, having a glass tube inside, the gas could be repeatedly exploded; but, as the lamp had always to be relighted, it might be considered an inconvenience for the workman to be left in the dark in a long working, when he would have to go to a place of safety to relight the lamp.

On the subject of the ventilation of coal-mines, he had no hesitation in saying that the area of the shafts ought to be quadrupled, in order properly to provide for the safety of the mine and for the health of the men. His opinion when a young man, and it had been borne out by subsequent experience, was that the so-called Government inspection of coal-mines was useless. The Inspector came after an explosion and went down the pit, and then told the men what they ought to have done, but he never told them beforehand what they should do to prevent an explosion. It was well known that in the present day in the north of England,

in Derbyshire, Lancashire, and Nottinghamshire, coal-mines were worked with one shaft with a brattice down the centre, one side being for the up-cast and the other for the down-cast. It could be judged what must be the state of the ventilation of those mines under such conditions. Let the Government Inspectors deal justice to all, and insist either upon a greater number of shafts, or upon shafts of a larger area. The price of coal might thereby be increased to a trifling extent, but that would be better than burning five hundred or six hundred men every year. He repeated that, for the quantity of coal got, the shafts ought to be quadrupled, either in area or in number.

On the subject of the long-wall system of working he would only say, it was a question of old prejudices and old feelings. He preferred one system, others preferred another. He believed if the system of working in some districts were changed, that the greatest difficulties would arise with the men. It was one of those old prejudices that could not easily be rooted out.

Mr. J. Knowles observed that, only a year or two ago, an Act was passed prohibiting the use of one shaft to a mine where more than twenty men were employed. There was an absolute necessity to have two shafts. He agreed that Inspectors should be persons qualified to give proper instructions to those who had charge of the workings—not sub-inspectors but men who could give good information.

Some experiments on temperature had been made by him in the Pendleton colliery. Mr. Bainbridge stated that a difference of temperature took place in descending, which he thought in a measure might be accounted for; because immediately the coal was opened out, a decrease of temperature took place. In that particular colliery it was found, that the large current of air passing along the main air-ways reduced the temperature of the mine very rapidly. That colliery had been worked for a long while on the long-wall system. The headings were driven to the further end, and the coal worked back so as to reduce the amount of face as much as possible. In his opinion, by working on the long-wall system, the commercial value of the coal was increased, and it could be brought into the market in a better state. He considered that collieries should be worked with naked lights; because if a mine was not in a fit state for naked lights to be employed, it was not fit for men to work in. He had advocated that plan for many years, and he still employed naked lights. At the same time a safety-lamp was used as a precaution, and every man went to his work with a safety-lamp; but previous to going into his working place, a fireman had gone round to see that it was safe. When safe the men could use a naked light throughout the day.

Mr. Bainbridge said, he was indebted to Mr. Knowles for the results he had given of the experiments made at the Pendleton colliery.

In regard to safety-lamps, the question, though foreign to the object of his Paper, was an important one. Whilst the Stephenson lamp had the advantage of becoming extinguished when exposed to the action of gas, it was objectionable on account of the bad light it gave. The Davy lamp showed a better light, and could not be considered liable to the danger alluded to, since a constant repetition of the action of firing the gas in the lamp would not be allowed to take place, a single test being sufficient to prove the presence of gas, and the danger of that part of the mine. Both the Stephenson and the Davy lamps, as well as the Clauny, had, however, been proved, by a series of experiments made by the North of England Institute of Mining Engineers, at which he had assisted, to be unsafe, where the current of explosive gas impinged upon the lamp at a greater velocity than about 30 feet per second; whilst the Mueseler lamp, in use in Belgian mines, stood this test without firing. Since this fact was ascertained, numerous safety-lamps had been devised, and several had proved to be safe, but the arrangement for effecting safety had the objection of obstructing, in some cases, the ingress of air to support combustion. Safety-lamps were certainly applicable to many mines where naked lights could not be used. This was the case in mines such as the Oaks, where sudden outbursts of gas occurred, and where falls of the roof occasionally dashed down gas congregated in the cavities caused by the falling in of the roof. It was one of the costly difficulties of mining, that accidents which seldom occurred had yet to be provided against.

May 31, 1870.

The Session was concluded by a CONVERSAZIONE, which was given by the President to the members of the Institution and to a numerous circle of distinguished visitors, when many choice works of art, and interesting engineering models and instruments, were exhibited, of which the following is a Catalogue:—

CATALOGUE OF WORKS OF ART

IN THE LIBRARY.

		Contributors.
1	IN THE MEADOWS. *G. Chester*	G. CHESTER.
2	IRON-MAKING IN KENT IN THE OLDEN TIME, SAY 1210. *J. Nasmyth, F.R.S.*	J. NASMYTH, F.R.S.
3	SEASIDE VIEW. *W. Collins, R.A.*	SIR D. GOOCH, Bart., M.P.
4	BED TIME. *W. P. Frith, R.A.*	F. T. TURNER, M. Inst. C.E.
5	STUDY OF THE PRINCIPAL HEADS IN PICTURE OF "LOST CHILD." *P. H. Calderon, R.A.*	G. SMITH.
6	LETTING THE COW INTO THE CORN. *T. Faed, R.A.*	F. T. TURNER, M. Inst. C.E.
7	VIEW ON THE HUDSON RIVER. *J. F. Kensett.*	A. H. BROWN, M.P.
8	CATTLE. *C. Troyon*	B. DOBREE.
9	DOLORES. *J. Phillip, R.A.*	H. ROUGIER.
10	THE SMOKER. *E. Meissonier*	J. FOWLER, M. Inst. C.E.
11	MORNING PRAYER. *Holman Hunt*	J. FOWLER, M. Inst. C.E.
12	FISHERWOMEN. *F. Burgess.*	G. F. GREGORY.
13	NEAR RICHMOND, YORKSHIRE. *T. Creswick, R.A.*	W. CAIRD.
14	MY SECOND SERMON. *J. E. Millais, R.A.*	J. SNOWDON HENRY, M.P.
15	THE EAGER TERRIER. *Sir E. Landseer, R.A.*	J. SNOWDON HENRY, M.P.
16	A PASSING STORM. *E. Verboeckhoven*	J. WHITEHEAD.
17	LANDSCAPE. *G. Morland.*	W. CAIRD.
18	VIEW IN IRELAND. *T. Creswick, R.A.*	W. CAIRD.
19	TWO CHILDREN. *E. Frère.*	J. SNOWDON HENRY, M.P.
20	CHARLES THE SECOND'S LAST SUNDAY AT WHITEHALL. *W. P. Frith, R.A.*	H. ROUGIER.
21	RED RIDING HOOD. *J. Sant, R.A.*	C. PRATER.
22	ROME, FROM THE GARDENS DELLA BARBERINI. *D. Roberts, R.A.*	J. SNOWDON HENRY, M.P.
23	AN INTERIOR. *E. Verboeckhoven.*	J. WHITEHEAD.
24	ON THE FRENCH COAST. *T. Creswick, R.A.*	W. CAIRD.
25	LEIGH WOODS, NEAR BRISTOL. — *Syers*	W. CAIRD.
26	AROUND THE BRASSERO. *J. Phillip, R.A.*	H. ROUGIER.
27	FRUIT. *W. Duffield*	D. THWAITES.

Contributors.

28 Una Maja Bonita. *J. Phillip, R.A.* F. T. Turner, M. Inst. C.E.
29 Scene from Milton's 'Comus.' *C. Stanfield, R.A.*
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30 Returning from the Mill. *Rosa Bonheur*
F. T. Turner, M. Inst. C.E.
31 The Windmill. *J. Linnell, Sen.* . . . C. Prater.
32 Breakfast Time. *T. Webster, R.A.* . . C. Prater.
33 The Herd Lassie. *R. Ansdell, A.R.A.* . A. H. Brown, M.P.
34 Venice. *J. M. W. Turner, R.A.* . J. Fowler, M. Inst. C.E.
35 Spring Time. *Vicat Cole, A.R.A.* . . . G. Smith.
36 The Labourer's Return. *W. P. Frith, R.A.* A. H. Brown, M.P.
37 Greenwich Hospital. *Canaletti* . . . . G. Smith.
38 A Breeze. *Backhuysen* . . . . . G. Smith.
39 Landscape. *Hobbema* . . . . S. Addington.
40 Sea View. *W. Vandervelde* . . . G. Smith.
41 Forest Scene. *Old Crome* . . G. Berkley, M. Inst. C.E.
42 Fruit. *G. Lance* . . . . D. Thwaites.
43 The Rainbow. *J. T. Linnell* . . . C. L. Collard.
44 Flowers. *Miss Mutrie* . . . . C. Prater.
45 Pasqueccio. *J. Phillip, R.A.* . . . H. Rougier.
46 Spanish Lady. *J. Phillip, R.A.* . . . C. Prater.
47 The Bird's Nest. *R. Carrick.* . . . T. Kell.
48 Rest by the Way. *P. F. Poole, R.A.* . . W. Caird.
49 Landscape. *P. Nasmyth*, 1823. . G. Berkley, M. Inst. C.E.
50 Morning Thoughts. *H. Schlesinger* . . C. L. Collard.
51 Dr. Hutton's Daughters, 1788. *Reinagle.*
C. B. Vignoles, Pres. Inst. C.E.
52 The Rising of the Nile. *F. Goodall, R.A.* . A. Burnand.
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55 Goody Two Shoes. *R. Carrick* . . . . T. Kell.
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57 York and Lancaster. *Miss A. Mutrie* . . C. Prater.
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59 Horses' Heads. *G. E. Herring* . . . D. Thwaites.
60 Our Saviour at the Well. *J. Linnell, Sen.*
Sir D. Gooch, Bart., M.P.
61 Fish. *W. Duffield.* . . . . G. F. Gregory.
62 Consolation. *A. Solomon* . . . . H. Rougier.
63 Lake Como on a Stormy Evening. *F. L. Bridell.*
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65 Group of Flowers. *J. Van Os* . . . G. Smith.
66 Dr. Hutton, Aged 86. *Reinagle*, 1822.
C. B. Vignoles, Pres. Inst. C.E.
67 Cattle. *T. Wainwright* . . . . D. Thwaites.
68 Wounded Dispatch Bearer. *J. Pettie, A.R.A.* T. M. McLean.
69 Andromeda. *W. E. Frost, A.R.A.* . . C. Prater.
70 Sea View. *G. Chambers* . Sir D. Gooch, Bart., M.P.

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71 The Lace Maker. *G. Smith* . . . G. Smith.
72 The Baptism of Our Lord. *J. Linnell, Sen.* C. L. Collard.
73 The Bashful Swain. *J. C. Horsley, R.A.* . C. L. Collard.
74 Incident in the Early Life of Greuze. *M. Stone.* C. L. Collard.
75 Sea Piece. *W. Vandervelde* . . . S. Addington.
76 Apple-roasting. *E. Frère* . F. T. Turner, M. Inst. C.E.
77 Grape Gatherer. *J. Phillip, R.A.* . . H. Rougier.
Ornamental Metal Work . . Skidmore's Art Company.

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*Marble Bust of the President . . . G. J. Miller.
77†Photographic Portrait of the President F. R. Window.
78 England. *G. Chester* . . . . C. L. Collard.
78*Bishop Percy's Visit to Goldsmith in Orange-tree Court. *J. Gow* . . . . . J. Gow.
78†Quiet Thoughts. *J. Gow.* . . . . J. Gow.
79 The Wreck. *R. Ansdell, A.R.A.* . . R. Ansdell, A.R.A.
80 Mill Water, Ockham, Surrey. *F. W. Hulme* F. W. Hulme.
81 The Lock. *Birket Foster* . . . . A. Tooth.
82 Horses. *G. Morland* . . . . . B. Dobree.
83 Portrait of the Artist. *D. Teniers.* C. J. Freake, Assoc. Inst. C.E.
84 Sheep. *G. Morland* . . . . . B. Dobree.
85 Straw Plaiters. *E. Ferroni* . . . H. Durlacher.

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86 Bridge Building at Blackfriars. *Edwin Edwards.* R. W. P. Birch, Stud. Inst. C.E.
87 Portrait of the late J. M. Rendel, Past President Inst. C.E. *W. Boxall, R.A.* . . . Mrs. Rendel.
88 Old Westminster Bridge, 1844. *C. Nixon.* C. Nixon, M. Inst. C.E.

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87 Illustrations of Autotype, or Permanent Fac Simile. The Autotype Company.
88 Under the Greenwood Tree—A Study in Arden. *F. H. Henshaw* E. Clark, M. Inst. C.E.
89 The Rustic Bridge. *W. Muller* . . . W. Caird.
90 Forest of Arden, Warwickshire. *F. H. Henshaw.* E. Clark, M. Inst. C.E.
91 The Brothers. *H. Campotosto* . . . T. M. McLean.
92 Water Gate at Haarlem. *A. Nasmyth* J. Nasmyth, F.R.S.
93 Madonna. After *Sasso Ferrati* . J. Snowdon Henry, M.P.

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96	Near Capel Curig. *D. Cox*	A. Tooth.
97	The Tambourine Player. *F. W. Topham*	A. Tooth.
98	Baldassare's First Madness. *E. J. Ellis.*	T. J. Ellis, Assoc. Inst. C.E.
99	Sea by Moonlight. *H. S. Marks.*	Hutton Vignoles, M. Inst. C.E.
100	Morning, near Gate Crag, Borrowdale. *R. T. Pain.*	A. C. Pain, Assoc. Inst. C.E.
101	Design for Frieze, the Prince's Theatre, Manchester. *H. S. Marks*	H. S. Marks.
102	The Trossachs. *W. Millais*	C. J. Freake, Assoc. Inst. C.E.
103	The Conference. *G. Bache*	C. L. Collard.
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105	Canterbury Cloisters *W. F. Yeames, A.R.A.*	W. F. Yeames, A.R.A.
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107	Morning, in the Schyn Pass, near Thusis, Switzerland. *R. T. Pain.*	A. C. Pain, Assoc. Inst. C.E.
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115	Jerusalem. *C. Werner*	W. Henderson.
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117	Washing at the Fountain. *F. W. Topham.*	C. L. Collard.
118	Broadwater Meadows. *H. S. Marks*	H. S. Marks.
119	Evening, Sils Canton, Switzerland. *R. T. Pain.*	A. C. Pain, Assoc. Inst. C.E.
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121	Riva degli Schivoni. A South Wind. *J. Holland.*	F. S. Teesdale.
122	Venice. *F. Walker*	A. Tooth.
123	Edinburgh, from the Costorphine Hill. *Mrs. Marrable.*	Mrs. Marrable.
124	Newhaven. *H. S. Marks*	H. S. Marks.
125	Still Life. *W. Duffield*	D. Thwaites.
126	The Stelvio Pass. *Mrs. Marrable*	Mrs. Marrable.
127	A Fresh Breeze. *C. Fielding*	A. Tooth.

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128 Faust and Marguerite. *E. Corbould.* C. J. Freake, Assoc. Inst. C.E.
129 Villa at Penmaen Mawr, North Wales. J. Fogerty, M. Inst. C.E.
130 Moonlight Scene. *R. Leslie* Hutton Vignoles, M. Inst. C.E.
131 Carpenter's Shop. — *Hayler* . . J. Nasmyth, F.R.S.
132 Original Sketch for Picture of Lady Jane Grey in the Tower. *W. F. Yeames, A.R.A.* W. F. Yeames, A.R.A.

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134 A Group of Boys. *M. Boucher.* T. H. Wyatt, Assoc. Inst. C.E.
135 Colonel Newcome in Grey Friars. *F. Smallfield.* F. Smallfield.
136 Morning. *E. de Richter* . . . T. M. McLean.
137 The Birthday. *Mrs. E. M. Ward* . . . C. Prater.
138 Afternoon. *E. de Richter* . . . T. M. McLean.
139 Portrait. *E. Williams* . . . . E. Williams.
140 Landscape, Figures. *W. Linnell* . . . A. Tooth.
141 Mount Orgueil Castle. *J. Webb* . . G. F. Gregory.
142 Cottage Door. *W. Cobbett* . . . . D. Thwaites.
143 Roman Galley. *J. E. Hodgson.* Hutton Vignoles, M. Inst. C.E.
144 The Derelict. *J. Webb* . . . G. F. Gregory.
145 Donkey Cart. *W. Cobbett* . . . . D. Thwaites.

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2 Cotton Gin . . . . . India Museum.
3 Model of Cotton Gin (Churka). From Arracan. India Museum.
4 Cotton Gin (Churka) . . . . . India Museum.
5 Rice Husking Mill . . . . . India Museum.
6 Cotton Gin (Churka). From Ulwar . . India Museum.
7 Model of Hand Mill . . . . . India Museum.
8 Spinning Wheel. From Kurrachee. . . India Museum.
9 Model of a Well. From Madras . . . India Museum.
10 Model of Persian Wheel. From Lahore . . India Museum.
11 Model of Man Weaving. From Belgaum. . India Museum.
12 Model of Chick or Blind Making. From Patna India Museum.

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13 Model of a Lever for Raising Water. From Patna . . . . . India Museum.
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15 Model of a Hand Mill . . . . . India Museum.
16 Model of a Rice Pounder (Dhenky). From Bombay . . . . . India Museum.
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19 Model of Bullock Garry carrying Rails in India. G. Berkley, M. Inst. C.E.
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23 Section of 7-inch Rifled Gun . . . J. Vavasseur.
24 Model of a continuous Lattice Girder Bridge . F. Fox.
25 Model of Moncrieff 9-inch Gun Carriage, on counterweight system . Captain A. Moncrieff, E.M.A.
26 Model of Hydro-Pneumatic Naval Gun Carriage. Captain A. Moncrieff, E.M.A.
27 Specimens of Band Saw Work . . S. Worssam & Co.
28 Model of proposed Wrought-Iron Breakwater. J. Dixon, Assoc. Inst. C.E.
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31*Model of Shield employed in Tunnelling under the Thames. P. W. Barlow, M. Inst. C.E.
32 Steel Pen Presses . . . . . W. F. Batho.
33 Specimens of Artificial Stone. Victoria Stone Works Company.
34 Specimen of New Zealand Free Stone. T. E. M. Marsh, M. Inst. C.E.
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36 Model of New Stone-cutting Tool. Patent Stone Working Company.
37 Model of Tunnelling Machine . . . J. D. Brunton.
38 Hydraulic Wedge for Getting Coal . . J. G. Jones.
39 Diamond Rock Borer. The Machine Tunnelling Company.
40 Composition for Lining Furnaces . . . E. Muller.
41 Patent Rail Testing Machine . . J. Price, M. Inst. C.E.
42 Model of Patent Pneumatic Stamps. W. Husband, M. Inst. C.E.
43 Patent Puddling Tools . . . . . A. P. Dormoy.
44 Model of Carr's Disintegrator . . J. P. Richardson.
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47 Model of Ventilating Machinery, Lime Street Tunnel, Liverpool . . J. Ramsbottom, M. Inst. C.E.
48 Patent Fire Brick Stove . . . . T. Whitwell.
49 Model of Truck with Bogie Frames, and Tramway. J. W. Grover, M. Inst. C.E.
50 Upright Boiler Feeder . J. C. R. Okes, Assoc. Inst. C.E.
51 Model showing adaptation of Howard's Safety Boiler to Marine Purposes . . J. & F. Howard.
52 Specimen of Malleable Cast Iron, twisted cold. W. H. Delano, Assoc. Inst. C.E.
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58 Models to illustrate the Causes of Boiler Explosions. E. B. Marten, Assoc. Inst. C.E.
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78 Knowles' Wrought Iron Permanent Way. W. Bellingham.
79 Model of Wrought Iron Permanent Way. Cockburn Muir.
80 Models of Permanent Way . . . . G. F. Griffin.
81 Models of Rails . . . . . W. B. Adams.

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84	Model of Hilf's Permanent Way.	T. A. Rochussen, Assoc. Inst. C.E.
85	Cushion Sleeper	W. Gregory.
86	Water Meter	J. A. Muller.
87	Samples of Steel Plates, Rail, and Angle Iron.	Schneider & Co.
88	Condensing Donkey Pump	A. Sauvée.
89	'Field' Boiler Tube from tug-boat 'Cobden'	L. Olrick.
90	Reducing Gear for Richard's Indicator	L. Olrick.
91	Automatic Boiler Feeder	T. Brown & Co.
92	Centrifugal Pump	C. Brakell.
93	Model of 12-inch Fan	C. Brakell.
94	Model of 12-inch Steam Fan	C. Brakell.
95	Durometer for testing the Hardness of Metals.	— Desgoffe.
96	Patent Gauge for Extreme Pressures	— Desgoffe.
97	Model of Two-story Railway Carriage	— Vidard.
98	Samples of Metal Work obtained from a Tube by direct Hydraulic Pressure without an Internal Die	H. Chapman.
99	Section of Steam Pressure Gauge	— Ducomet.
100	Model of Screw Propeller	— Mangin.
101	Self-registering or Tell-tale Water Gauge	G. Firmin.
102	Models of Cleats and Blocks	A. Paget.
103	Model of Brakes	— Stilmant.
104	Plummer Block	— Varlet.
105	Model of Fog Steam Trumpet, with a Reed of full size	— Lissajoux.
106	Weldless Steel Chain	— David.
107	Domestic Steam Engine	— Fontaine.
108	Specimens illustrating the Flow of Solids	— Tresca.
109	Diving Machine Air Pump	Siebe & Gorman.
110	Model of Sewage Extractor	B. Latham, M. Inst. C.E.
111	Pipe for the Distribution of Sewage.	B. Latham, M. Inst. C.E.
112	Model of Combined Manhole Cover and Ventilator for Sewers	B. Latham, M. Inst. C.E.
113	Chronoscope, for recording at one observation the velocity with which a projectile passes different parts of the bore of a gun	Capt. A. Noble.
114	Royal Polytechnic Barometer	Davis & Co.
115	Reed and Bowen's Combined Punch, Shearer and Upsetter	Towle & Harding.
116	Engine for Steam Launch	Yarrow & Hedley.
117	Model of Retort Setting	T. N. Kirkham, M. Inst. C.E.
118	Self-acting Water Crane	Stothert & Pitt.
119	Twin Screw Engines	John & Henry Gwynne.

Contributors.

120 Upward's Safety Drilling Apparatus as applied to Water Mains under Pressure.
EASTONS, AMOS, & ANDERSON.
121 The Hinkley Single Needle Knitting Machine. J. KEIGHLEY.
122 Model of Power Loom for Weaving Worsted Fabric, Alpacas, Mohairs, &c. . . J. KEIGHLEY & Co.
123 Half Model of H.M.S. 'Inconstant'.
E. J. REED, C.B., M. Inst. C.E.
124 Half Model of the 'Fethi Bulend,' Turkish Frigate . . . THE THAMES IRON WORKS COMPANY.
125 Gassiot's Electrical Fountain . . . A. APPS.
126 New Electrical Counting and Coin or Check Registering Apparatus . . . . A. APPS.
127 Ten-inch Spark Induction Coil . . . A. APPS.
128 Four-inch Spark Induction . . . . A. APPS.
129 New Series of Rotating Vacuum Tubes and Improved Electro-Magnetic Engine . . A. APPS.
130 Electrical Coronet . . . . . A. APPS.
131 Glass pierced by an Electrical Discharge . A. APPS.
132 Improved Magneto-Electric Mine Exploder . A. APPS.
133 Model of Floating Bath . . J. DIXON, Assoc. Inst. C.E.
134 Model of Section of H.M.S. 'Devastation.'
E. J. REED, C.B., M. Inst. C.E.
135 Model of Section of H.M.S. 'Rupert.'
E. J. REED, C.B., M. Inst. C.E.
136 Models of Section of H.M.S. 'Bellerophon.'
E. J. REED, C.B., M. Inst. C.E.
137 Model of Steam Life Ship . . . CAPTAIN HANS BUSK.
138 Model of a Twin Channel Steamer . . A. SEDLEY.
139 Cartridge Loading and Turning-over Machine J. NORTHCOTE.
140 Steam Lubricators . . . . . P. JENSEN.
141 The 'Nautilus' Life Belt . . . . MAW & Co.
142 Model of Buddle for Separating Ores . J. H. WILLIAMS.
143 Model of Baxter's Automatic Weighing Machine.
T. BROWN & Co.
143*Miners' Safety Lamp . . . . . J. A. HOGG.
144 Model of Multiple Needle Sewing Machine for making Thatch . . . . . G. O. GOODAY.
145 Model of Dutch Iron-clad Monitors, 'Heiligerlee' and 'Krokodil.' . . . . LAIRD BROTHERS.
146 Silver's Marine Engine Governors . . W. GREGORY.
147 Model of Dutch Iron-clad Ram 'De Stier.' LAIRD BROTHERS.
148 Model of H.M. Steam Turret Ship 'Captain.' LAIRD BROTHERS.
149 Model of Weighing Crane . . . . A. SAUVÉE.
150 Balanced Rudder . . . . . C. G. GUMPEL.
151 Antiquities from Tumuli, near Kertch.
C. W. SIEMENS, M. Inst. C.E.
152 Electrical Thermometer and Pyrometer.
C. W. SIEMENS, M. Inst. C.E.

		Contributors.
153	Model of Endless Rail and Wheel . . .	E. H. Newby.
154	Model of Deep Water Screw Pile Pier.	H. N. Maynard, M. Inst. C.E.
155	Experimental Cast-Iron Cylinder.	Sir J. Whitworth, Bart., M. Inst. C.E.
156	Experimental Cast-Iron Cylinder, with Wrought Iron Tube inside	Sir J. Whitworth, Bart., M. Inst. C.E.
157	Experimental Whitworth-Metal Cylinder.	Sir J. Whitworth, Bart., M. Inst. C.E.
158	Model of Humphreys' Post and Railway.	J. Samuel, M. Inst. C.E.
159	Illustrations of Joinery: Panels of old Oak, from Sherwood Forest . . .	G. Smith & Co.
160	Model of Hydraulic Steering Apparatus as applied to H.M.S. 'Achilles.'	Rear-Admiral Inglefield, C.B.

IN HALL AND LOBBY.

161	Fountain	Jabez James, Assoc. Inst. C.E.
162	Velocipede . . .	J. B. Meredith, Assoc. Inst. C.E.
163	Model showing Improvements in the Covering of Roofs	G. Jennings.
164	Model of Cistern for the Prevention of the Waste of Water	G. Jennings.
165	Model of Exhausting Machine for Ventilating Mines	J. Cooke.

APPENDIX TO VOL. XXX.

MEMOIRS.

HENRY, BARON BROUGHAM AND VAUX, of Brougham, in the county of Westmoreland, was born at Edinburgh on the 19th of September, 1778. He was the eldest son of Henry Brougham, Esq., by Eleanor, only daughter of the Rev. James Syme, D.D., of Alloa, and niece of the celebrated historian, Dr. Robertson. In his boyhood Henry Brougham was sent to a school kept by a Mr. Luke Fraser, where also Sir Walter Scott and Lord Jeffrey were in part educated. At the age of fifteen he entered the University of Edinburgh, and in 1794 attended the lectures of Professors Playfair and Robison. After leaving the University, and becoming admitted a member of the Society of Advocates, he travelled in Holland and in Russia, and on his return took up his abode in his native city, where, in 1802, he assisted in the establishment of the "Edinburgh Review." In 1803 he was elected a Fellow of the Royal Society of London, on account of his numerous contributions to science. He was called to the English bar in 1807, chose the King's Bench for his practice, and attached himself to the northern circuit. The numerous and important legal cases in which he was engaged do not enter within the scope of this short notice, but the leading part taken by him in the trial of Queen Caroline cannot be passed over without mention.

In 1810 he entered the House of Commons as Member for Camelford. At the general election in October, 1812, he unsuccessfully contested Liverpool, and subsequently the Inverkeithing Burghs, and for four years he was out of Parliament. From 1816 to 1829 he represented the borough of Winchelsea, which seat he resigned, but was in a short time elected for Knaresborough. He sat for the county of York in 1830, together with Lord Morpeth (afterwards the Earl of Carlisle) and the Hon. William Duncombe. On the 1st of April, 1819, he had married Mary Anne, the eldest daughter of Mr. Thomas Eden, niece of the first Lord Auckland and the first Lord Henley, and widow of Mr. John Spalding. In 1823 he founded the London Mechanics' Institute; in 1825 he was elected Lord Rector of the University of Glasgow; and in 1827 he was mainly instrumental in establishing the "Society for the Diffusion of Useful Knowledge," contributing to the first volume an introduction "On the Objects,

Advantages, and Pleasures of Science." On the 22nd of November, 1830, he took his seat in the House of Lords as Lord High Chancellor, being created a peer of Great Britain, by the title of Baron Brougham and Vaux, on the following day. His official life ended in the year 1834; but he continued for some time to take an active part in politics, as well as in matters relating to the amendment of the law and in social science; was in 1859 elected Lord Rector of the University of Edinburgh; in June, 1860, received the honorary degree of D.C.L. at Oxford, and his complete retirement into private life only dates from 1866. At the time of his death, which occurred at his seat at Cannes, in the south of France, on 7th of May, 1868, in the ninetieth year of his age, he was a Member of the Institute of France, and was President of the University College, London, of the Law Amendment Society, and of the Social Science Congress. He was elected an Honorary Member of the Institution of Civil Engineers on the 28th of June, 1842, "because of his literary and scientific attainments, and his eminence as an author."

This brief chronicle can only indicate a few of the principal epochs in the career of one who has been described as a walking encyclopædia;—as a man who knew a little of everything, and of many things everything;—as a statesman, an orator, a man of science, a metaphysician, a historian, an essayist, and a lawyer;—as distinguished in every branch of knowledge;—and whose strong, practical, energetic and versatile mind was devoted to the great reform of the constitution, to juridical reforms, particularly to improvements in the criminal law, and who gave an impetus to education among all classes, especially by aiding in the production of cheap and useful books, and whose literary labours embraced discourses on political economy, philosophy, science, and biography.

Dr. PETER MARK ROGET, F.R.S., was born in London, on the 18th of January, 1779, and was the only son of the Rev. John Roget, a Genevese clergyman at that time settled in London as minister of a French Protestant church in the City. His mother was the sister of Sir Samuel Romilly, who not only held her husband in the warmest esteem, but was wont to attribute to Roget's early prediction of his professional success the choice of that path in life which he afterwards trod with such distinction. Mr. Roget did not live to superintend his son's education. He died in Switzerland when his son was but four years old, and the task devolved upon his widow, who appears to have brought to it an exceptional degree of intelligence and judgment. Some of the rudiments of learning were acquired at a private school kept by a Genevese friend, M. Chauvet, in Kensington Square; and, at the

age of fourteen, the boy commenced his studies at the University of Edinburgh. He had already shown a decided taste for mathematics, and had begun to teach himself the elements of science. The choice of medicine as his profession did not impose a limit upon his range of study, and he listened with as lively an interest to the discourses of Dugald Stewart, as to the lectures which he attended, with equal diligence, in the medical school. At the age of nineteen, he took his degree of M.D., and showed his predilection for scientific research by selecting, as the subject of his thesis, the laws of chemical affinity. His name appears before the beginning of the century as a writer on medical subjects, for there is a letter from him on pulmonary consumption, published in 1799 in Dr. Beddoes's Essay on that disease. Another letter of his was published in the following year by Davy, on the respiration of nitrous oxide.

Among the friends and instructors of his youth, there was perhaps no one to whom he confessed greater obligations than his uncle's esteemed friend Dumont, and it was probably through that channel that Dr. Roget made the acquaintance of the philosopher Jeremy Bentham. In the autumn of 1800 he was, at Bentham's invitation, an inmate in his house for six weeks, for the purpose of assisting him with advice in a project described in Bentham's words as a "Frigidarium; a sort of ice house for the purpose of preserving fermentible substances of all sorts from prejudicial fermentation, by excluding the degree of heat necessary to that process." The scheme does not however appear to have led to any practical result.

During the short peace of Amiens, he accepted an engagement to travel on the Continent, in charge of two young men, the sons of Mr. John Philips, of Manchester. In the spring of 1803 the three travellers were enjoying themselves at Geneva, when Dr. Roget suddenly found himself a French prisoner, being included under Napoleon's order to arrest all the English within his dominions; from which liability the two young Philips's were held exempt, as being under eighteen. Dr. Roget was on the point of being sent with the other prisoners to Verdun (there to remain till the restoration of 1814), when he claimed and obtained his release by insisting that, as the son of a citizen of Geneva, he was entitled to the rights of a French subject. These rights did not, however, include that of quitting the country, and they moreover involved a liability to the conscription. Dr. Roget therefore seized the opportunity afforded him by the grant of a passport for Paris, to escape with his young friends across Switzerland, and get them back to England as best he could, through Germany and Denmark.

After attending the Marquis of Lansdowne for some months as his private physician, he was, in October, 1804, appointed one of

the physicians to the Manchester Infirmary, which office he held for four years. Encouraged by success there, particularly in awakening an interest, by means of lectures, in the then dawning science of comparative physiology, he removed to London, where, on the 3rd of March, 1809, he was admitted a licentiate of the College of Physicians (of which he became a fellow in 1831), and entered into a practice which in a few years became considerable. He soon established himself also as an able expositor of his favourite science of animal physiology, in a series of courses of public lectures, which extended over a period of more than thirty years. He also at that time took a leading part in the establishment of the following institutions connected with his profession—the Northern Dispensary, of which he was acting physician for eighteen years; the Great Windmill Street School of Medicine, where he lectured for five years on the Practice of Physic; and the Medico-Chirurgical Society, of which he was secretary for seventeen years, and president for two years. He also held for many years the post of physician to the Spanish Embassy.

Dr. Roget became known as a practical mathematician by his invention, in 1814, of a sliding rule for performing the operations of involution and evolution of numbers, on principles similar to those of the common sliding-rule for obtaining products and quotients. In Dr. Roget's instrument, the rule or fixed line is marked in degrees proportioned to the second logarithms (or logarithms of logarithms), while the slider retains its graduation on the scale of simple logarithms, of the natural numbers. On a single setting for a given number, the rule or fixed line exhibits the whole series of powers of that number corresponding to the exponents marked on the slider. That this must be the case may be seen in the general formula, $\log . \log a + \log m = \log . \log a^m$. By reversing the slider, the series of roots may be similarly displayed; and the rule may also be used to find the exponent of a given power, and to solve other problems, such as the interpolation of mean terms of a geometric series. Among the various applications of which it is susceptible may be mentioned the calculation of compound interest, the solution of questions relating to the increase of population, the doctrine of chances, the radiation of heat, the transmission of light, and the density of gases under pressure. A full description of the instrument, with suggestions of other modes in which the logo-logarithmic scale may be employed mechanically for similar purposes, is contained in Dr. Roget's paper on the subject in the "Philosophical Transactions" for 1815. This paper gained for its author admission to the Royal Society, with which body his name was afterwards long associated as one of its secretaries. He held that office from 1827 to 1848.

In 1823 Dr. Roget and Dr. Latham were appointed physicians

to the Millbank Penitentiary on the occasion of an epidemic dysentery which had broken out there. The result of their labours appeared in a Report to the House of Commons in the following year.

In 1824 Dr. Roget married Miss Hobson, daughter of a Liverpool merchant. He was left a widower with two children in 1833.

On the 25th of June, 1827, a Royal Commission was issued to Dr. Roget, Mr. Brande, and Mr. Telford, to inquire into the state of the supply of water in the metropolis, it being already evident, from the disappearance of fish and other symptoms, that the river Thames was suffering a gradual deterioration. The result of their inquiries, and of a series of analyses performed under their direction by Dr. Bostock, was, that the water was susceptible of improvement by filtration, but that it ought to be supplied from other sources than the tidal portion of the Thames. To their report, dated 21st April, 1828, is also appended a mass of information collected with a view to providing a remedy for the state of things then existing, which shows that the commissioners were fully prepared to prosecute an inquiry in that direction had the Government of the day thought fit to afford them the means of doing so. Their recorded opinion led, however, to the adoption of a system of filtration, and subsequently to the Act of 1852, forbidding the water companies to draw their supplies below Teddington Lock.

On the 27th of March, 1838, Dr. Roget, being at the time Secretary to the Royal Society, was elected an Honorary Member of the Institution of Civil Engineers "on account of his high scientific attainments." He was also an Honorary Member of the Smeatonian Society of Civil Engineers. At this time he was actively employed on the senate of the University of London, in the foundation of which body he took great interest, and for which he was for some years examiner in physiology and comparative anatomy. He was a member of nearly all the learned societies of London, and of numerous foreign academies.

Dr. Roget's published works, the dates of which are scattered over a period of no less than seventy years, embrace subjects so distinct from one another, that they afford a measure of his versatility of mind as well as extent of information. Although, during his life, his reputation as a writer was mainly founded on his admirable "Bridgewater Treatise," on "Animal and Vegetable Physiology," the first edition of which came out in 1834, it seems probable that his name will be better known to future generations by the work of his old age, his "Thesaurus of English Words and Phrases." This is a philosophical arrangement of words so disposed as to exhibit, in their appropriate groups, the resources of the language which are available for the expression of any given idea. Very early in life Dr. Roget had assured himself of the

utility of such a work, by compiling for his own use a small vocabulary on the same system. His retirement from professional practice, and from the secretaryship of the Royal Society, at length gave him time to take up this design and carry it into effect. The work was first published in 1852, since which time the demand for it has steadily increased, and its value is becoming more and more widely acknowledged. Of his other writings, the major part are on subjects connected with his profession, viewed in all cases under the light of science and philosophy. He contributed various articles to the "Encyclopædia Britannica," the most important of which is a treatise on "Physiology," which was also published separately, together with his article on "Phrenology," in which 'pseudo' science he was a declared unbeliever. In 1827-31, he wrote a series of treatises on "Electricity, Galvanism, Magnetism, and Electro-magnetism," for the Society for the Promotion of Useful Knowledge, of which he was an active member. His familiarity with these branches of science had already appeared in his article in the "Quarterly Review" for 1826, on "Electro-magnetism," and in that entitled "Galvanism" in the "Encyclopædia Metropolitana."

Of Dr. Roget's minor writings, the following may with propriety be here noticed:—The article "Kaleidoscope," in the supplement to the sixth edition of the "Encyclopædia Britannica;" and a letter on the same subject, dated 3rd April, 1818, published in the "Annals of Philosophy," vol. xi., p. 375, in which the writer draws attention to the advantages of that form of the instrument in which three mirrors are employed, and determines the conditions of its manufacture. An appendix to Larkin's "Solid Geometry and Crystallography" (1820), in which Dr. Roget demonstrates the ratios subsisting between the volumes of the solids composing the artificial series, together with the inclinations of their faces. In the "Annals of Philosophy," N.S., vol. i., p. 135, is a letter dated 25th Jan., 1821, from Dr. Roget, in which the writer points out a material error in Mr. Perkins's account of his experiments on the compressibility of water. In the "Philosophical Transactions" for 1825, p. 131, is a curious paper by Dr. Roget on "An Optical Deception in the Appearance of the Spokes of a Wheel seen through Vertical Apertures." To the "Scientific Gazette" for 1825, pp. 259, 277, Dr. Roget contributed a paper "On an Apparent Violation of the Law of Continuity," in which he proposed the following paradox: If an elliptic hoop be supposed to be subjected to a force of compression in the direction of the major axis, and the action of this force be continued until the curve, passing through the form of a circle, opens out in a transverse direction, the major axis becoming the minor, the motion of each of the two foci would seem to be discontinuous, its direction changing suddenly at a right

angle, after the foci have merged in the centre, at the moment when the ellipse takes the form of a circle. In the "Journal of the Royal Institution" for 1831 is an article by Dr. Roget "On the Geometric Properties of the Magnetic Curve, with an account of an Instrument for its Mechanical Description." The writer gives simple demonstrations of the fundamental propositions belonging to the curve, derived directly from the law of magnetic forces, and shows how it may be traced on paper by means of the property that the difference of the cosines of the angles made by the radii with the axis is a constant quantity. The "London and Edinburgh Philosophical Magazine" for April, 1840 (vol. xvi.), Article li., is a "Description of a method of moving the Knight over every square of the Chess-board, without going twice over any one; commencing at any given square, and ending at any other given square of a different colour. By P. M. Roget, M.D., Sec. R.S." It is an ingenious and complete solution of a problem which had exercised the ingenuity of mathematicians for a hundred years without a like success.

Dr. Roget also contrived, in 1845, a chess-board with movable card men, which admits of being folded up and carried in the pocket without disturbing the state of the game. It bears the name of the "Economic Chess-board," and is particularly adapted to the use of amateurs of chess problems. In contrivances such as this Dr. Roget's ingenuity was continually at work. He had a natural taste for mechanism. At the meetings of the British Association his favourite section was that devoted to mechanical science, and it must be in the remembrance of many Fellows of the Royal Society with what interest he regarded the Swedish calculating machine when it was exhibited at Somerset House by the late Mr. Gravatt. Few persons were then aware that he had himself projected and made some progress in constructing the model of an engine designed with the same object.

Although, in Dr. Roget's scientific researches, the doctrine of utility, which had been impressed upon him in early life by his friends, Dumont and Bentham, was ever present to his mind, he was also incited to their pursuit by an innate and ardent love of his subject for its own sake. He would exhibit the same keen relish for analysis undertaken in the construction of a toy as when employed in the establishment of a physical principle; the same lively interest in mechanical contrivance, when amusing his friends with an optical illusion, as when working in the same field with Babbage and with Scheutz. In his mode of describing the kaleidoscope of Sir David Brewster, for example, one may easily detect an acquaintance with the niceties of its construction, which was gained by personal experiments in its manufacture. His mind, thus constituted, was never at a loss for resources, and an habitual

industry characterised him to his last day. In old age, when debarred by deafness from the enjoyment of society, and when external events made less impression upon him than in former days, he long derived amusement from work which would demand from most men considerable application of mind; investigating difficult problems in optics, playing with permutations and combinations, and composing four-move stratagems of chess of acknowledged beauty and merit. A few years before his death he made considerable progress with a set of tangible or ocular demonstrations in plane geometry, such as proving the Forty-seventh Proposition of the First Book of Euclid by means of three pieces of card, which, differently placed together, would form either the square on the hypothenuse or the sum of the squares on the sides.

It was chiefly in such employments as these, pursued during his serene retirement from the world, that an indication remained of what he had been in the prime of life, at a period which few of his many friends are now living to recall. Those among them who knew him best can say with confidence that no man was more benevolent at heart, more unaffected in word or deed, or more steadfast in the simple following of what he held to be right. These qualities were accompanied by an unvarying gentleness of demeanour, a natural courtesy that was no respecter of persons, and an unselfish spirit that ever restrained him from imposing upon others the task he was himself able to perform.

Dr. Roget's general writings are much esteemed for elegance of style; and his treatment of subjects which do not afford scope for literary ornament is no less remarkable for perspicuity and correctness. He took a real pleasure in the mere neatness of execution of any work in hand, however trivial; and his firm, clear handwriting, invaluable to a mathematician, was the delight of compositors. When he applied himself to a task, he strove to accomplish it thoroughly; never sparing himself trouble, though ever fertile of resources for the economy of labour; but apparently following out the principle, that what is worth doing at all is worth doing well.

Dr. Roget's death was unattended by suffering. It occurred on the 12th of September, 1869, at West Malvern, where he had been spending the summer. A grey granite slab in the country churchyard now marks his resting-place, and records the great age of ninety years, to which he lived.

The Rev. WILLIAM WHEWELL,[1] D.D., was born at Lancaster, on the 24th of May, 1794. He received the first rudiments of instruction at the grammar-school in that town; and having from his earliest years manifested a remarkable fondness for reading, and exhibited general promise of future ability, he was removed to the grammar-school at Heversham, where he obtained an exhibition for admission to Trinity College, Cambridge, of which he became a sub-sizar in the October term of 1812, was subsequently elected as a full, or foundation sizar, and soon after received a scholarship. In 1813 he obtained the Chancellor's prize for the best English poem on the subject of Boadicea; and in 1816 he graduated as second wrangler and Smith's prizeman. In the year after his graduation as B.A. he was elected a fellow of his college, and he remained closely associated with it up to the date of his death. He was for many years an eminent and successful tutor. At the time when he began to assume an active part in University education, the definite study of physics was virtually superseded by mathematics, under the idea that the latter included everything necessary to be known of the former. Dr. Whewell threw himself into the reform of the university mathematics, with Peacock, Herschel, and Babbage. He wrote an "Elementary Treatise on Mechanics" (1819), a "Treatise on Dynamics" (1823), an "Introduction to Dynamics," "First Principles of Mechanics," and "Treatise on the Free Motion of a Point for Universal Gravitation" (1832), an "Elementary Treatise on Mechanics," and "Analytical Statics" (1833), and "Mechanical Euclid" (1837), to which list was attached a section "On the Logic of Induction." By these works, and by the influence which, as moderator, in the years 1820, 1828, and 1829, he was enabled to exercise on the course of the examinations for degrees, he contributed materially to that improvement he so much desired to see established in the mathematics of the university. It was on the 23rd of May, 1837, that he was elected an Honorary Member of the Institution of Civil Engineers. In 1828 he had been appointed Professor of Mineralogy, a post he held for five years. In 1838 he accepted the Professorship of Moral Philosophy, and he founded prizes for the encouragement of that study, which he himself always pursued with avidity. He retained the chair until 1855, in which year he was elected Vice-Chancellor of the university. In 1841 he was appointed by the Crown, Master of Trinity, and in this position he took an active part in introducing into Cambridge the new studies which have since been recognized

[1] The "Proceedings of the Royal Society of London," vol. xvi., 1867–68, contains a very interesting memoir of the Rev. Dr. Whewell, signed J. F. W. H. [Sir John Herschel], from which this notice has been in a great measure taken.

by the institution of the Natural and Moral Sciences Triposes. In 1819 he assisted in the foundation of the Cambridge Philosophical Society, and to the Transactions of that society he was a frequent contributor. In 1821 he was made a Fellow of the Royal Society, in the labours of which he took a prominent part, and his fourteen "Researches on the Tides," which were printed in the "Philosophical Transactions" between the years 1833 and 1850, and for which a Royal Medal was awarded in 1857, are regarded as highly interesting and valuable. In 1827 he became a fellow of the Geological Society, and filled the office of President in 1838; and in the Transactions of that body will likewise be found several of his Papers. He was an early supporter of the British Association for the advancement of Science, over which he presided at Plymouth in 1841, and the reports of that association contain many memoirs from his pen, including Reports on the Tides, and on the Mathematical Theories of Heat, Magnetism and Electricity, which rank among the first of his mathematical productions. He had previously written, in 1833, the Bridgewater Treatise "On Astronomy and General Physics," and it was, perhaps, this which suggested to him the "History of the Inductive Sciences," published in 1837, followed in 1840 by "The Philosophy of the Inductive Sciences," since expanded into "The History of Scientific Ideas," the works by which, it is believed, he will be best known in after years. Besides these, his principal works were "The Mechanics of Engineering" (1841), "Architectural Notes on the German Churches" (1842), "Indications of the Creator" (1845), written in answer to the "Vestiges of the Creation," "Elements of Morality," "Lectures on the History of Moral Philosophy in England," "Lectures on Systematic Morality" (1846), "Novum Organum Renovatum" (1858), "Chapters Critical and Historical on the Philosophy of Discovery" (1861), and "The Plurality of Worlds," which last, however, did not appear under his name. He also translated Goethe's "Herman and Dorothea," Auerbach's "Professor's Wife," Grotius on the "Rights of War and Peace," and Plato, under the title of "Platonic Dialogues for English Readers."

Dr. Whewell was twice married, and twice a widower. His first wife was the second daughter of John Marshall, Esq., of Patterdale, Cumberland. That lady died in 1854. He married, secondly, in 1858, the widow of Sir Gilbert Affleck, who died on the 1st of April, 1865. Dr. Whewell's death occurred on the 6th of March, 1866, from the effects of a fall from his horse, in the seventy-second year of his age, and after a residence of more than half a century in Cambridge, where "his towering figure was one of those soonest known by the undergraduate, who had heard of his renown long before he came into residence; and when he

quitted the university at the end of his career, the Master of Trinity was the man above all others whom he remembered as the representative of Cambridge learning and Cambridge dignity."[1]

Mr. FRANCIS BAIRD,[2] the second son of Mr. Charles Baird, the founder of the celebrated 'Baird Works,' at St. Petersburg, was born on the 16th of February, 1802. After being educated at the University of Edinburgh, he joined his father's works at the age of seventeen, and entered zealously into the business there originated. He was elected into the Institution of Civil Engineers on the 25th of February, 1823, as a Corresponding Member, a class which differed only in name from that of Member, and the two were incorporated in one class by special resolution passed at a General Meeting of Members, held on the 26th December, 1837. In October, 1828, he married Dorothea, the second daughter of the late Mr. John Halliday, and by this marriage had ten children, of whom three only survived him. From the period of Francis joining his father, to the death of the latter in 1843, the two were associated in business, and on the occurrence of that event, Francis became, and continued to be, the sole proprietor, until his own death on the 25th March, 1864.

Numerous public and private works were executed at the Baird foundry, including the machinery for the Imperial arsenal and the Imperial glass-works, suspension bridges, the slip for hauling up vessels on the tideless shore of the Gulf of Finland, numerous steam-vessels, steam-engines by which various manufactories, saw and flour mills, wool, cotton, and flax mills, rope-works, &c., were set in motion. The nature of these works, and the length of time required for their completion, were such as to extend beyond the period of the joint exertions of father and son, so that some of them ultimately devolved solely on Francis. Amongst the public works may be specially mentioned the share taken in the construction of the column erected to the memory of the Emperor Alexander I. in the centre of the square of the Winter Palace, and also of the St. Isaac's Cathedral, at St. Petersburg — two of the most remarkable edifices of modern construction—the former higher than the Napoleon column at Paris, or the pillars of Trajan and Antonine at Rome, or of Pompey at Alexandria; the latter intended to rank with the cathedral of St. Paul in London, St. Peter at Rome, St. Sophia at Constantinople, and other similar grand temples in Europe. The four bas-reliefs on the base of the

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[1] "The Times," March 7, 1866.

[2] Abridged from a "Memoir of the late Charles Baird, Esq.; and of his son, the late Francis Baird, Esq.;" printed for private circulation, of which a copy is deposited in the Library of the Institution C.E.

Alexander column, the four eagles at the angles of the pedestal, the four candelabra at the corners of, and the bronze railing round the monument, and the colossal figure of the angel holding a cross, upwards of twenty feet in height at its summit, were all executed at the Baird Works by a then novel process, and in a foundry specially erected for the purpose, from designs composed by the architect, the late M. de Montferrand, assisted by the sculptors MM. Swintzoff, Lepec, and Orlowski. The two furnaces in this foundry were each capable of melting 24,000 lbs. of copper in two hours and a half, and there were two cranes each of which were capable of lifting a weight of 40,000 lbs.; they were used principally for moving the moulds for the process of casting. Most of the bas-reliefs and figures were cast in one piece. The rebuilding of the St. Isaac Cathedral was likewise entrusted to M. de Montferrand, who engaged the services of the Bairds in the construction in bronze of the bas-reliefs, the colossal figures, and the gilded dome and cupola which adorn that remarkable building. The bas-reliefs in the four fronts of this cathedral, weighing 800,000 lbs., the figures in bronze, each 15 feet 2 inches high, representing the Twelve Apostles, the statues in bronze round the exterior colonnade of the dome, the construction in iron, covered with plates of polished copper, of the gilded dome, 130 feet in diameter, and the bases and capitals in bronze, both in the interior and the exterior of the cathedral, were all made at the Baird Works, and so well were they executed, as to elicit the warmest encomiums from the architect. Amongst other works of a public nature may be named the Blagavetchari (usually called the St. Nicholas) bridge, which was the first permanent structure of the kind across the Neva. This last was the work of Mr. Francis Baird alone, as well as others of great utility after his father's death; indeed the business increased to such an extent that many marine engines of 800 H.P. were made at those works, which were in all respects similar to establishments of a like kind in England.

Many and high orders of distinction were conferred on both father and son in Russia, including those of St. Anne, of Vladimir, of the second order of Stanislaus, and of others. They were honoured with Imperial visits—no slight distinction in Russia—from three successive Emperors, and from the present Grand Duke Constantine. Like to his father's nature and conduct through life, Francis Baird's was of the most generous, open-handed mould. His end was sudden. He was warmly attached to and beloved by his family, and hurried to England to pay the last tribute of love and respect towards a daughter whose untimely end had thrown upon all who knew her the deepest and most enduring grief. He returned to St. Petersburg in health, but within one month he was attacked with fatal illness, and died just after attaining his sixty-second year.

Mr. WILLIAM CARPMAEL was born in London, on the 27th February, 1804. After receiving a mercantile education, he became an assistant in the laboratory of Mr. Kellerman, a chemist, at Luton, in Bedfordshire. There he remained about two years, and obtained a knowledge of the rudiments of chemistry. He afterwards became a pupil of the late Professor Millington, with whom he studied for some years, and under whose supervision he prepared, amongst other things, the working drawings for the bridge over the river Thames at Great Marlow, the erection of which he also superintended. Subsequently he designed and erected salt-works in Cheshire for the late Mr. Furnival, and these works he managed for some time. Having, however, become connected with the late Mr. Poole, the Attorney-General's clerk of the Patents, with whom he entered into partnership in 1835 as a patent agent and consulting engineer, he ceased to occupy himself with the constructive branch of engineering. The general knowledge of law, which he now required, was obtained by reading with a special pleader, the late Mr. Colman, of the Temple. He also qualified himself for the bar, and, though never called, was a member of Lincoln's Inn. In the consideration of engineering questions he specially excelled by his rapid and firm grasp of new mechanical ideas, and by the closeness and accuracy with which he was able to define them. Every one engaged in matters connected with patents knew that Mr. Carpmael was a strenuous and persistent advocate for an amendment in the Law of Patents, that he took an active part before the various Committees of the Houses of Parliament on Bills to promote that object, and that he published several useful and practical works bearing on the subject of patents for inventions.[1]

Mr. Carpmael was elected an Associate of the Institution of Civil Engineers on the 16th of March, 1830, served on the Council in the year 1838, was transferred to the class of Members on the 14th of June, 1840, and for many years was a constant attendant at the meetings, and took part in the discussions. He was also a Member of the Royal Institution, and of the Institution of Mechanical Engineers, and an Associate of the Institution of Naval Architects. On the formation of the Metropolitan Board of Works he was elected a member of it, and remained so until his death, taking an active part in the promotion of the projects for the Main Drainage of London and for the Thames Embankment. Mr. Carpmael died on the 9th of July, 1867, in the sixty-fourth year of his age.

[1] *Vide* "The Laws of Patents, familiarly explained" (this has passed through many editions); and "Law Reports of Patent Cases."

Mr. JOHN CLARK was born at Bristol on the 13th of September, 1831. He commenced his professional career under Mr. Charles Underwood, Architect, of Clifton, and was then for a short time engaged under the late Mr. George Aitchison (Assoc. Inst. C.E.). He was afterwards employed for about two years under Mr. Vignoles, F.R.S. (Pres. Inst. C.E.), on the Frankfort, Wiesbaden, and Cologne railway, and next, for nearly six years, again under Mr. Aitchison. He then entered the service of the Great Northern Railway Company, and was for three years an Assistant at King's Cross, in the office of the Engineer, and for two years was principal Assistant Engineer, under Mr. Brydone (M. Inst. C.E.), and Mr. Richard Johnson (M. Inst. C.E.), respectively. In 1863 he went to China, and was for three years Engineer to the Municipal Council of Shanghai, for whom he carried out drainage works, river embankments, timber bridges, floating and other jetties, etc. In 1866 he came to this country, his health being much impaired, but he returned to China in the following year, and was appointed "Assistant Surveyor-General" at Hong Kong, with permission to take private business. He died of heart disease, from which he had been a sufferer for some months, on the 16th of October, 1868, in his thirty-eighth year, and was buried in the cemetery at Hong Kong.

He was elected a Member of the Institution of Civil Engineers on the 8th of January, 1867, and a Fellow of the Royal Institute of British Architects on the 28th of January, 1867. Actuated by a high sense of duty, possessing considerable professional knowledge and experience, and being extremely painstaking and careful, his death was a great loss to the colony, where he seems to have been universally loved and respected.

Mr. THOMAS DUNCAN was born on the 4th of December, 1804, in the city of Perth, where his father carried on the business of a builder and contractor. After having served a regular apprenticeship as a practical mason under his father, he was engaged at the bridge of Perth, and on the works of the Leeds and Bradford canal; he was then, for two years and a half, one of the assistant engineers on the Hull and Selby railway, where his constructive talent and aptitude for mastering difficulties attracted the attention of the late Mr. James Walker (Past President Inst. C.E.). During the next two years and a half he was employed by Messrs. Walker and Burges to superintend, as resident Engineer, the construction of lighthouses at Hunstanton, in Norfolk, and at Great Fern (the subsequent scene of Grace Darling's famous exploit), and at Langstanes, in Northumberland. The deficiency in the supply of water for extinguishing fires, and for other public

purposes, and the occurrence of a series of great conflagrations in 1840, raised an adverse feeling in the town against the water companies, and induced the Commissioners of Highways to seek for parliamentary powers to draw water from the docks or river, or to obtain a supply from the red sandstone for the extinguishing fires, supplying baths, watering streets, and other public purposes. They obtained the powers they sought in the session of 1843. The late Mr. James Simpson, Past President Inst. C.E., was the engineer entrusted with the works, and he, having witnessed the skill displayed by Mr. Duncan in carrying out the various works referred to, induced him to become his resident engineer in Liverpool. In the summer of 1844 these works were commenced by the sinking of a well and working shaft at Green-lane, and constructing a spacious reservoir at Kensington, and were successfully completed under Mr. Duncan's care about the close of 1846. In April, 1847, the Corporation appointed him assistant to Mr. Newlands (M. Inst. C.E.), Engineer for the borough under the Liverpool Sanatory Act of 1846.

The Corporation had obtained powers in 1846 to purchase the works of the existing Water Companies, and to construct an extensive system of artificial lakes to collect the rainfall of the neighbourhood of Rivington Pike, and to bring it to Liverpool, a distance of twenty-four miles, by gravitation, a scheme of which Mr. Hawksley, Vice-President Inst. C.E., was the engineer. Under these powers the works of the Bootle and Harrington Companies, and of the Highway Board, passed into the hands of the Corporation, and were temporarily managed by Mr. Scott and by Mr. Newlands; but in 1850 Mr. Duncan was appointed manager of all the waterworks of the borough. The carrying out of the Rivington Pike scheme, under the Act of 1846, was strongly opposed by a large party of the inhabitants, who believed that an adequate supply of water could be obtained at a much less cost from the red sandstone of the district. This opposition gave rise to a long delay and a memorable controversy as to the relative merits of obtaining the supply of water from the sandstone on the spot, or of deriving it from surface gatherings elsewhere; at length the whole question was referred to the late Mr. Robert Stephenson, who, in 1850, issued a report which decided the Corporation to carry out Mr. Hawksley's scheme. The works were let in five contracts, and were carried out under the immediate superintendence of Mr. Duncan, who, in 1855, at the request of the water committee, successfully completed the formation of filter beds and the construction of two very large reservoirs, which one of the contractors failed to perform. When, in 1858, Mr. Hawksley retired from the position of Engineer-in-Chief, on the completion of his original design, Mr. Duncan was

placed in sole charge of all the water-works, at a competent salary, which was subsequently increased. In the interim, several extensions and improvements, derived from experience, were designed and carried out by Mr. Duncan, in the appliances for supplying half a million of people in Liverpool and its suburbs with water. Among these may be named the reservoir at Roddlesworth, another at Prescot, besides important alterations in the construction and working of the great filter beds at Harwich. When the tenders for the Roddlesworth reservoir were opened by the water committee, it was found that they were much in excess of the estimates made by Mr. Duncan, who was thereupon requested to undertake the supervision of the erection, by which a saving of several thousand pounds was effected. Of the works in the town, he designed and constructed the reservoir at Toxteth Park, the reservoir at Aubrey-street, Everton, begun in 1853, with its surface and town tanks—the latter a striking architectural feature, novel in conception, and combining beauty and utility. The main object of this construction is to obtain a high-pressure service in all parts of the town, and it is said to have been one of the chief means, combined with an active fire brigade, of saving Liverpool from those disastrous conflagrations which formerly, at frequent intervals, ravaged the neighbourhood of the docks and warehouses. The extension of the works at Green-lane, the construction of the great reservoir at Woolton, in 1864, and of the new pumping station at Dudlow-lane, and also one at Bootle, were likewise due to Mr. Duncan.

During the whole of the time that Mr. Duncan was an officer of the Corporation of Liverpool, he devoted himself to his work with an energy, a single-mindedness, and an ability which could not be surpassed. He was esteemed as much for his social qualities, his probity, and his kindness of heart, as for his intimate practical knowledge of all the details of his profession, and for his scientific acquirements,—qualities which, combined with a clear and vigorous intellect, were eminently shown in the works produced from his designs, or executed under his superintendence, and in the numerous special reports which he was called upon from time to time to furnish to the Corporation of Liverpool.

Mr. Duncan's connection with the Institution of Civil Engineers dates from the 6th of June, 1848, when he was elected an Associate. He was transferred to the class of Members on the 26th of January, 1858, having in the interim furnished an original communication, descriptive of the Liverpool Corporation Water-works, which was read in the session 1852-53,[1] and for which a Telford Medal was awarded.[2] His decease occurred on the 3rd of December, 1868, after a protracted illness of four months, brought on

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 460.
[2] *Ibid.*, vol. xiii., p. 162.

by hard work, and within one day of attaining his sixty-fifth year. His remains were interred in the Smithdown-lane cemetery, in the presence of a numerous assemblage of sorrowing friends, who by this last sad act testified their respect for the memory of the deceased, and the high esteem in which he had been held both in public and in private life.

Mr. JOHN GODWIN was born at Swansea. His early studies led him to adopt engineering as a profession; and having, by his talent, and his industrious habits, attracted the attention of Sir James M'Adam who introduced the system of road-making distinguished by his name, Mr. Godwin was taken, at the early age of fourteen years, under his care and patronage. Mr. Godwin remained with Sir James M'Adam between five and six years, and during that time was intrusted with the superintendence of several engineering works in various parts of the south of England. This engagement terminated on Mr. Godwin's being appointed Surveyor to the Camberwell Trusts, London, when he received a valuable present from Sir James as a mark of appreciation and esteem. After a few years he became the Surveyor and Engineer to the Liverpool and Preston turnpike roads, and remained in charge of those roads for a period of eight years, residing at the time at Ormskirk. His energy was not however confined to the duties of this appointment, but he was also engaged in the execution of various works in North Lancashire. In the year 1836 he removed from Ormskirk to Belfast, on being appointed Engineer to the Ulster railway. The works were originally limited to the line between Belfast and Lisburn, and were designed by the late Mr. Thomas Woodhouse, M. Inst. C.E. Before the works had progressed very far, the originators of the scheme resigned, and the new Directors determined to appoint another Engineer. A deputation from the Board of Directors accordingly proceeded to Manchester, the then centre of railway enterprise and management, in order to select an efficient Engineer, and their choice fell upon Mr. Godwin, not merely on account of the high reputation he enjoyed, but also from his unpretending and unobtrusive address. Mr. Godwin continued to act as Engineer-in-chief of the Ulster railway until 1862, during which period he was occupied in extending the line from Lisburn to Portadown, and afterwards to Monaghan and Armagh. He was associated with several other railways in Ireland,—as the Engineer-in-chief of the Belfast and County Down, the Newry and Enniskillen, and the Newry and Warrenpoint railways, the engineering and Parliamentary difficulties of which were very considerable.

He was the first Professor of Engineering in Queen's College, Belfast; but he resigned that, as he did other appointments, some

years before his death. Although during his earlier life he was actively engaged in the duties of the profession, he still found time to cultivate his taste for the fine arts. He was a ready and accomplished draughtsman, and a very good painter in oil and water colours, for both of which he had considerable talent, and which proved a great source of occupation and enjoyment to him in his leisure hours.

He was possessed of great kindness of heart, and though at all times ready and anxious to help the industrious, and to assist those in distressed circumstances, his dislike to anything bordering on ostentation or display rendered his many acts of benevolence unknown to any save the recipients of his assistance and bounty.

Mr. Godwin died at Tamnagharrie, in the County of Down, on the 15th of January, 1869, having lived but three years in the residence which he purchased on his retirement. It may with truth be said that his life was exemplified by all those qualities which adorn a scientific, practical, and honest man.

He was elected a Member of the Institution of Civil Engineers on the 24th of June, 1845, but owing to his constant residence in Ireland, he was not able to be a frequent visitor at the meetings, in the proceedings of which he, however, took a lively interest.

Mr. ALEXANDER GORDON was the second son of Mr. David Gordon, the inventor and patentee of the system of compressing gas and using it in a portable form, and the grandson of Sir Alexander Gordon, of Culvennan, Greenlaw, Castle Douglas. He was born at New York (where his father at that time resided) on the 5th of May, 1802. At the age of five years he returned with his father to Scotland, and was subsequently educated at the Edinburgh University. In early life he was much employed by Telford, and was on intimate terms with the Messrs. Bramah, Donkin, Field, Simpson, and other members of the Institution. For many years he was agent for Mr. R. Napier, the marine engineer at Glasgow, and he was also manager of the portable gasworks in London, until they were abolished. Mr. Gordon devoted himself principally to the construction and management of lighthouses, especially in the colonies. In 1833 he introduced a polyzonal arrangement, both dioptric and catadioptric, constructed by M. Maritz, of the Hague; and, in the same year, the catadioptric apparatus of Fresnel, which he adopted for lighthouse purposes, and which he exhibited at a meeting of the British Association at Edinburgh in the following year. This he followed up in 1834 by patenting a holophotal apparatus; and in 1842 he designed and erected the original great sea-light in an iron tower at Morant Point, Jamaica, the first of many of a similar character. In the lighthouses erected by Mr. Gordon, he preferred using multiple reflectors, so that if

through accident or carelessness one or two of the lamps were extinguished, there were still sufficient left to maintain the light. In 1837 Mr. Gordon published a treatise on locomotion, which passed through three editions, and was translated into several languages. He also, in 1845, patented a fumific propeller. Besides the branches of engineering already enumerated, he designed and superintended the construction of the South Australian Company's swing bridge at Port Adelaide, which was made at the manufactory of Messrs. Easton, Amos, and Sons. Mr. Gordon was one of the originators of the Polytechnic Institution with Sir George Cayley and several other gentlemen, the object of the Institution being, at that time, entirely scientific. He was highly esteemed in private life; and many of his pupils acknowledged that they owed their success in life to the instruction and advice received from him.

He was elected an Associate of the Institution on the 10th of April, 1827; was transferred to the class of Members on the 17th of February, 1835, and contributed a Paper on "Photography, as applicable to Engineering," in the year 1840.[1] After that date he frequently took part in the discussions at the evening meetings. He was also a Fellow of the Royal Geographical Society. Mr. Gordon died at Sandown, Isle of Wight, on the 14th of May, 1868, in the sixty-seventh year of his age.

Mr. DANIEL GALLAGHER GROSE was the only son of the late Arthur Grose, Commander R.N., and was born in November, 1828. He was intended for the Royal Engineers, but delicate health retarded his studies until he was past the age for admission to the Royal Military Academy at Woolwich. After serving a regular period of pupilage at Plymouth, under the late Mr. A. H. Bampton, M. Inst. C.E., he was engaged for three years upon the South Devon and Tavistock railway, as Resident Engineer, then for three years on the South Devon railway, having charge of the works for doubling a portion of the line; and afterwards, for two and a half years, on the Launceston and South Devon railway, as Resident Engineer, having entire charge of the works during their construction. On these recommendations he was elected a Member of the Institution on the 5th of February, 1867. In May, 1866, he went to Sulina for a few months to assist Sir Charles A. Hartley, M. Inst. C.E., in preparing the project for the improvement of the port of Odessa, which carried away the first prize; and he re-engaged himself to him in the spring of 1868, to aid in getting up detailed plans for the formation of a Roumanian seaport, connected with the Danube by means of a ship canal. He

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 57.

began work on the 6th of July, and was occupied until the 14th of August in surveying a marshy district to the north of the Sulina mouth, where it is proposed to cut a canal of communication between the Danube and the sea. On the 15th he came to Sulina suffering slightly from diarrhœa. On the following day dysentery set in, and carried him off on the 24th, notwithstanding the assiduous care of nurses, and the best medical aid the locality could afford. Mr. Grose married, in 1859, Charlotte, widow of the late S. H. Cornish, Esq., whom he survived. He left two children to mourn his loss. Sir Charles Hartley, in writing to the Secretary, says, "I feel his sudden death keenly; for not only did he possess all the qualities one could desire in a confidential assistant, but what is rarer still, he had the ring of true metal about him, which made every one who saw much of him reckon upon and love him as a friend."

Mr. JOHN HENRY HARTWRIGHT was born in the county of Worcester, and served a regular apprenticeship under Mr. John Marks, of Cirencester. He was then employed for several years at the Swindon Works of the Great Western railway, and was subsequently engaged in the construction and erection of pumping-engines at the Hayle Foundry, Cornwall, at Elbœuf (France), at Mons (Belgium), and at the Liverpool Waterworks. In 1845 he was appointed Superintendent of Works for the Manchester and Salford Waterworks Company, and for the four years ending in the spring of 1854 he had charge of the pumping station at Gorton, which had become the property of the Manchester Corporation. In May, 1854, he was appointed Resident Engineer for the extensions of the Chester Waterworks under Mr. Bateman (M. Inst. C.E.), for whom he also acted as Resident Engineer in the construction of the new works for the supply of water to Wolverhampton, from Cosford Brook, and to Birkenhead, from a well at Flaybrick Hill, and he was likewise actively occupied on many other works. He was elected a Member of the Institution of Civil Engineers on the 1st of December, 1868, and he died at Barcelona, in Spain, on the 1st of May, 1869, whither he had gone to superintend, for Mr. Bateman, the erection of some pumping machinery for the drainage of lands forming part of the right delta of the river Ebro. Mr. Hartwright may be said to have been a self-educated man, having acquired most of his scientific knowledge while occupied in active work; he was both an excellent practical and theoretical mechanical engineer. He was a diligent student of nature, especially in the department of entomology, and a numismatist, and had formed valuable collections of insects and of coins; but he was of a very reticent and retiring disposition, and was little known beyond the sphere of his official duties.

Lieutenant-General Sir HARRY DAVID JONES,[1] G.C.B., D.C.L., R.E., one of five sons of John Jones, Esq., General Superintendent at Landguard Fort, was born at that place on the 14th of March, 1791, and he became a cadet at the Royal Military Academy, Woolwich, on the 10th April, 1805. After a probation of six months, on the Ordnance Survey of England, as "Candidate for the Corps of Royal Engineers," he was, on the 17th September, 1808, gazetted second lieutenant, and was, for a short time, employed in the superintendence of works of fortification at Dover. In the next year he took an active part in the attack and reduction of the fortress and arsenal of Flushing; and although a sufferer from the Walcheren fever, proceeded immediately afterwards to Spain, where he served under Lieut.-General Sir Thomas Graham, in the defence of Cadiz, as first lieutenant, to which rank he was promoted on the 24th June, 1809. From Cadiz he was despatched, under Colonel Stewart, for the relief of Tarragona (1811), and he joined the army under the Duke of Wellington, then engaged in the siege of Badajos (1812), and took part in all the ensuing campaigns, until the termination of the Peninsular War, in 1814. For his bravery at the battle of Vittoria he was recommended for promotion; and he was wounded and taken prisoner while leading the forlorn hope at the first assault of St. Sebastian. He was sufficiently recovered to again take his place in the fifth division in the battle of Nivelle (1813); and for his conduct then, and in the operations at the passage of the Bidassoa, Nive, and before Bayonne, he received the thanks of the Master-General of the Ordnance. On the 12th November, 1813, he was promoted to the rank of second captain. In February, 1814, he was attached to Sir John Lambert's expedition against New Orleans, at Dauphine Island; and in the following year he joined the Duke of Wellington's army before the capture of Paris, was in command of the Engineers at Montmartre, and was made a commissioner to the Prussian army of occupation in 1816. He received the silver war medal with five clasps. On his return to England in 1818 he was employed in various routine duties at Plymouth, Jersey, and Chatham. In the summer of 1826 he was promoted to the rank of captain, and was sent to Malta, from whence he was employed on services on the coast of Africa, and on special duty at Constantinople, in 1833-34. In May, 1835, he returned home, on being appointed Commissioner for Municipal Boundaries in England, and in November of that year he was employed in the improvement of the navigation of the river Shannon. On this commission he was

[1] Mainly abridged from a Memoir by Lieut.-General H. Sandham, R.E., in the "Professional Papers of the Corps of Royal Engineers," vol. xvi. New Series. Woolwich, 1868.

engaged for several years, besides being First Commissioner for fixing the Municipal Boundaries in Ireland, and Secretary to the Irish Railway Commission, which latter office he held when elected a Member of the Institution of Civil Engineers, on the 25th April, 1837. He was then for a short time Commanding Royal Engineer at Jersey; but he was soon again removed from the corps, to take up the appointment of Commissioner for the Improvement of the Navigation of the river Shannon; and in 1845 he became the Chairman of the Board of Public Works in Ireland, the duties of which office he continued to perform until 1850. He had been made brevet-major on the 10th of January, 1837, and attained the rank of lieutenant-colonel on the 7th of September, 1840. In 1842 he communicated to the Institution some observations "On the Forms of Breakwaters, with Suggestions for their Modification,"[1] which led to a very interesting discussion. In 1843 he consented to edit a third edition of the "Journal of the Sieges carried on by the Army under the Duke of Wellington in Spain, during the years 1811 to 1814." In 1849 he presented to the Institution a "Description of the Bridge erected at Athlone, by the Commissioners for the Improvement of the river Shannon,"[2] for which useful record of a large work successfully executed he received a Telford Medal.[3] In 1851 he was selected to fill the important position of Director of the Royal Engineer Establishment for Field Instruction at Chatham. At the commencement of the war against Russia, in 1854, he was appointed brigadier-general for particular service in the Baltic, and commanded the British forces at the siege operations against Bomarsund, in the Aland Isles. For his conduct in the Baltic he was promoted to be a major-general. In February, 1855, he assumed the command of the Royal Engineers in the Crimean campaign, which he retained until the fall of Sebastopol. He was wounded in the forehead by a spent grape-shot, on June 18th, 1855. In the course of that year he received the following distinctions and decorations, viz., K.C.B. (being advanced to be a G.C.B. in 1861), first class Military Order of Savoy, the Order of the Medjidie of the second class, the Sardinian war medal for military valour, the Cross of Commander of the Legion of Honour of France, the Turkish medal for services in the East, besides the Baltic medal, and the medal and clasp for the Crimea, from the British government. He was brought to England in enfeebled health, in consequence of the wound and incessant fatigue; but he was sufficiently recovered in the following year (1856) to return to duty. As a recognition of his devotion to the varied and important trusts confided to him for forty-eight

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 124.
[2] *Ibid*, vol. viii., p. 296. [3] *Ibid*, vol. ix., p. 95.

years, he was placed on the list of officers receiving rewards for "Distinguished or Meritorious Services," and in May of the same year (1856) he was appointed Governor of the Royal Military College, and of the Staff College at Sandhurst. On the 6th of July, 1860, Sir Harry became a lieut.-general, and on the 2nd of the following month he was appointed a colonel commandant in the corps of Royal Engineers. For about a year prior to his decease the state of his health continued to excite the gravest apprehension among his family and friends, and at last, on the 2nd of August, 1866, in his seventy-fifth year, he sank from sheer exhaustion, esteemed, admired, and regretted by all who had the happiness to know him.

Mr. ALFRED KING, the youngest son of Mr. Joseph King, the compiler of the well-known "Tables of Interest," was born in Liverpool on the 24th of December, 1797. From an early age he showed great interest in mechanical pursuits, and gave clear indications of his fitness for the profession which he afterwards adopted. Having received his education at a private school in Liverpool, he remained in that town until the year 1824, when he removed to London, and was engaged at the engineering works of Messrs. Taylor and Martineau, until 1826. During this period he superintended the erection of gas apparatus in various parts of the kingdom, and had to contend with many of the difficulties attending the first introduction of gas. In 1826 he was appointed Engineer to the Liverpool Gas Company, on the death of his brother John, the previous Engineer to the Company, and this position he retained until his own death, which took place, after a lingering illness, on the 27th of April. 1867. For nearly forty-one years, therefore, he had occupied that responsible position, and those who were associated with him during that long period can alone fully understand his devotion to his work, as well as the self-sacrificing spirit he ever showed to further the interests of the company, with which he was so long and so honourably connected, and to promote the cause of science to the utmost of his ability. Mr. King was remarkable for the thoroughness and accuracy of his work, entering into every detail, and never sparing time or trouble to render everything he undertook as perfect as possible. He won the entire confidence of those by whom he was professionally consulted, and while his courteous manners and sterling integrity made him deservedly esteemed by those who were only slightly acquainted with him, he is remembered by those who knew him well as a warmhearted and affectionate friend.

Mr. King will always be identified with the history of gas-lighting. He was perhaps the first to pay attention to the

adoption of a regular systematic plan in the construction of gas-works, and the establishments designed by him are models of convenient arrangement and order. He was the inventor of the delicate pressure-gauge, which bears his name, for indicating small amounts of pressure,[1] and of the photometer, now almost universally employed for ascertaining the illuminating power of gas. The use of bored and turned joints for pipes was successfully employed by him when a large amount of prejudice existed against that system, and by the application of gas for cooking, which he suggested, an additional source of revenue was opened to gas companies. Although his attention was chiefly occupied with the special branch of the profession with which he was more immediately connected, he nevertheless was deeply interested in all branches of engineering. During the construction of the Liverpool and Manchester railway, and as the friend of the late George Stephenson, Joseph Locke, and others, his advice was often sought; and among other inventions connected with this undertaking may be mentioned a system of telegraphic communication, by means of compressed air, between the Edge Hill and the Lime Street stations, Liverpool. Among his last inventions was a self-registering barometer, now used at the Liverpool Observatory; an instrument which was only brought to its present perfection after much thought, and a long series of preliminary experiments.

Mr. King's connection with the Institution of Civil Engineers dates from the 25th of February, 1840, when he was elected an Associate "on account of his scientific acquirements, and his connection with engineering pursuits, having the direction of the gas-works at Liverpool." On the 5th of May following he was transferred to the class of Members, when his qualifications were more precisely set forth as follows: "Because he is engaged as a practical Engineer, is the Engineer of the Liverpool Gas-works, and has made many beautiful experiments on subjects connected with railways—the evaporation of water, consumption of fuel, &c." Mr. King's scientific attainments and his practical knowledge were so sound and so varied, that he would have shone in any branch of the profession, and it is to be regretted that he did not extend the sphere of his action.

Mr. MICHAEL LANE was born on the 26th of October, 1802, in London. His professional career commenced at the Thames Tunnel in the year 1825, when he joined the staff of Sir M. I. Brunel (M. Inst. C.E.). From 1832 to 1834 he was engaged at the Bristol Docks as Resident Engineer, under Mr. I. K. Brunel (V.P.

[1] A short account of this instrument is given in the Minutes of Proceedings Inst. C.E., vol. ii. (1843), p. 192.

Inst. C.E.), and from thence he was transferred to the Monkwearmouth Dock, Sunderland (north shore), which he carried out, also for Mr. Brunel, and where he remained until December, 1840. He then first became connected with the Great Western railway, acting as an assistant to Mr. G. E. Frere, the Resident Engineer of the western division of that line; but two years later he accepted the appointment of Resident Engineer to the Hull Docks; which position he occupied until August, 1845, when he rejoined the Great Western Railway Company, and became superintendent of permanent way of a division of that line. He continued to be so engaged for a period of fourteen years; when, on the retirement of Mr. Bertram (M. Inst. C.E.), at the close of 1860, subsequent to the death of Mr. Brunel, Mr. M. Lane was made the Engineer to the company, and retained that office to the day of his death, on the 27th of February, 1868, in his sixty-sixth year. It is said that for the last five years he had been more or less troubled with Bright's disease, and had been enjoined not to overtax his powers. He had the reputation of possessing a thoroughly practical knowledge of the details of the execution of public works, and as a man was much esteemed by a large circle of friends and acquaintances for his kindliness of disposition combined with honesty and integrity. His remains were interred at Kensal Green cemetery, where a large number of the officers and staff of the company, in whose service he had spent so many years of his life, assembled to pay the last tribute of respect to their departed colleague.

He was elected a Member of the Institution of Civil Engineers on the 5th of February, 1861.

Mr. GEORGE LOWE[1] was the son of a brewer at Derby, where he was born about the year 1788, and in which town he was for some years engaged in his father's occupation. His attention was at an early period directed to illumination by coal gas; and several articles written by him on the subject, which appeared about fifty years ago in Tilloch's Philosophical Magazine, showed that he had considered the question with a clear and comprehensive mind. The knowledge he displayed of the science of gas-making seemed to fit him peculiarly for undertaking the duties of gas engineer, and in 1821 he was appointed one of the engineers of the Chartered Company, which was then beginning to make known the advantages to be derived in the metropolis from the introduction of gas lighting. That office he continued to hold until the year 1862, when, in consideration of his long and

[1] This notice has been mainly taken from "The Journal of Gas-lighting" for Jan. 5, 1869.

valuable services, the Directors of the company gave him a retiring pension equal to the full amount of his salary. Mr. Lowe married about three years before his engagement as Engineer to the Chartered Company, and he lost his wife, to whom he was devotedly attached, in 1843.

Mr. Lowe was elected an Associate of the Institution of Civil Engineers on the 29th of April, 1823, and was transferred to the class of Members on the 2nd of June, 1829. He served on the Council from 1837 to 1845, both years inclusive, and took a very active part in the discussions at the Ordinary General Meetings, as is shown by a reference to the early volumes of the 'Minutes of Proceedings.' In 1835 he was elected a Fellow of the Royal Society, for which honour he was chiefly indebted to the production of Prussian blue from ammoniacal liquor and from the refuse lime liquor of gas-works, specimens of which, produced by him, attracted the notice of H. R. H. the Duke of Sussex, who was at that time President of the Society. Mr. Lowe entered actively into various fields of scientific inquiry, and was elected a Fellow of the Geological, of the Chemical, and of the Microscopical Societies, and he was also elected a corresponding Member of the Franklin Institute, which was an honour he much prized, on account of its having been conferred on him without his knowledge. In addition to the responsible office of Engineer of the Chartered Gas Company, Mr. Lowe fulfilled at the same time the duties of Consulting Engineer of the Imperial Continental Gas Association, of the European Gas Company, of the Dublin Alliance Gas Company, and of many other gas companies at home and abroad.

The activity of Mr. Lowe's mind developed itself in numerous inventions for improving the manufacture and the illuminating power of gas, of which the Patent Office contains the records. The first invention patented by Mr. Lowe was that known as his "reciprocating retort," dated October 12, 1831. In that invention long retorts were first employed. The usual charge of coal was put in at each end of the retort to half its length, so that the gas of inferior illuminating power evolved from the charge of coal first introduced might mix with the richer gas evolved from the charge introduced subsequently. The same patent comprised the introduction into the furnace of highly-heated atmospheric air, for the purpose of igniting the gases and vapours arising from the lime and ammoniacal liquors placed under the bars of the furnace, the products of which were to be conducted into condensers to produce sulphurous acid, to be afterwards applied to purifying the gas. The specification of the patent further included a means of generating hydrogen gas by passing steam through the incandescent coke withdrawn from the retorts, the gas produced being afterwards enriched by the process since called carburetting.

In the next patent, dated June 9, 1832, the process of carburetting was applied to increase the illuminating power of ordinary coal gas, and with it was combined a process for the production of Prussian blue from ammoniacal liquor and from the refuse lime liquor. A third invention included in the same patent consisted in a means of collecting the tar, of different degrees of specific gravity, by self-acting syphons placed at different parts of the condenser.

Seven years afterwards a joint patent was obtained in the names of George Lowe and John Kirkham, which comprised five inventions. The first was a modification of Mr. Lowe's reciprocating retort, applied to a combination of several retorts. The second invention was a combination of clay and iron retorts, which principle has since been extensively amplified by others. The third related to a mode of applying heat to retorts, during the first hours of distillation, by means of a blast of air into the ash-pit of the furnace. The fourth invention consisted in a mode of employing tar as fuel, by mixing breeze with the tar, which was then introduced into a retort, and the distilled products were conveyed by a pipe to the fire in the furnace. The fifth invention specified in the same patent consisted in setting the retorts nearly vertically, and so arranged as to be charged at the upper ends, and from time to time drawn at the lower ends. The novelty of this invention is described as consisting "in so constructing such retorts as to cause the gas evolved from the fresh charges to descend, and pass amongst the highly-heated charges, and mix with the gas evolved therefrom."

In March, 1841, Mr. Lowe was again in the Patent Office, with an invention for "improved methods of supplying gas under certain circumstances, and of improving its purity and illuminating power." The specification of this patent was divided into five parts, the first three of which related to improvements in gas-meters, and included Mr. Lowe's motive-power meter, and a means of purifying gas in passing through meters by the introduction into them of alkaline solutions. The fourth part related to the purification of gas in dry purifiers, by causing the gas to pass over a series of shallow trays, containing sponge impregnated with a caustic alkaline solution. The fifth part of the invention consisted in a mode of increasing the illuminating power of coal gas, by passing it over similar shallow trays containing sponge impregnated with naphtha.

A fifth patent, dated Oct. 8, 1846, was granted to Mr. Lowe for "Improvements in the manufacture and in burning gas, and in the manufacture of fuel." In this invention blocks of dried peat were immersed in melted resin or pitch in a closed vessel, from which the air was pumped out, to form a material for making

gas. It included, also, the application of revolving perforated pipes for distributing water or purifying liquor in gas washers; and the improvements in burning gas consisted in the adjustment, by screws, of the air supplied internally and externally to the flame of an Argand burner, a button being employed internally to deflect the air on to the flame, and the conical shape of the chimney caused the current of air to be directed on the flame externally.

The last appearance of Mr. Lowe's name in the records of the Patent Office is on the 20th of January, 1852, when, in conjunction with Mr. F. J. Evans (M. Inst. C.E.), he patented an invention for the purification of gas by "anhydrous peroxide of iron," the energies of which might be repeatedly renewed by exposure to the atmosphere. This patent was dated four days before that of Mr. Hills for the purification of gas by hydrated oxides.

These various patented inventions for improving the manufacture of gas prove that Mr. Lowe's powers of mind were remarkably active and inventive, and that he possessed extensive knowledge of the principles on which the production and purification of gas depend. It will be seen from this cursory survey of his ingenious and well-devised plans, that many subsequent inventors and patentees have derived from Mr. Lowe not only their ideas but the methods by which they were practically applied. In addition to those inventions which he secured by letters patent, Mr. Lowe contrived many other very useful appliances which he gave to the public, among which may be mentioned the bladder-valve, now found so useful in preventing the escape of gas during the laying of mains; and his "jet photometer" is to be found in all well-managed gas-works. It is not, however, by his inventions alone that Mr. Lowe's influence on the progress of gas lighting is to be estimated. His sound judgment, his varied and practical scientific knowledge, rendered him an authority to be applied to in all questions of doubt: whilst his amiable disposition and courteous manners imparted additional value to his opinions and advice.

Mr. Lowe had long suffered from a tendency to congestion of the lungs, and his life had been prolonged only by the most careful precautions, which latterly involved almost entire seclusion; but to the last he retained the cheerful and genial disposition which had endeared him to a large circle of professional and private friends, and which secured respect even from those who differed from him. A long, valuable, and honourable career was closed on Christmas Day, 1868, at his residence in St. John's Wood Park, London, in the eightieth year of his age.

Mr. JOHN RICHARD MANBY, the second son of the late Mr. Aaron Manby (M. Inst. C.E.), was born at Wolverhampton, on the 10th of October, 1813. He received his education at the Pensionnat Massin, Paris, and was at an early age placed in the gas-works of Messrs. Manby, Wilson, and Co., in that city, where he gained a good knowledge of that branch of the profession, and simultaneously studied general construction, chemistry, mining, &c. He was then for several years engaged in the construction of the Cette and Montpellier railway, and in the erection of iron-works in the south of France.

He returned to England about the year 1839, and practised his profession in South Wales, where he was engaged in laying out large general works in the coal district, and he subsequently spent a short time in London. He then became the Resident Engineer of some iron-works in Spain, and afterwards joined his younger brother Edward in business at Madrid. Thence he removed to Paris, and was engaged in the working of lead-mines at St. Martin la Sauveté. He subsequently accepted an offer to manage the mercantile affairs in Italy of a London firm, and settled first at Genoa and then at Turin, where he materially benefited by the change of climate. In spite, however, of every care, the symptoms of pulmonary disease, from which he had previously suffered, again appeared, and after lingering for a considerable period, he died suddenly at Turin from the rupture of a blood-vessel, on the 19th of March, 1869.

He was of a kind, genial temperament, and possessed the enviable secret of rendering himself a favourite wherever he went. He was followed to the grave by kind-hearted French and Italian friends, who had, during his illness, vied with each other in generous attention to him, and who mourned for him as for a relative.

He joined the Institution of Civil Engineers as a Graduate in the year 1840, and was transferred to the class of Members on the 2nd of May, 1854.

Mr. JOHN MATTHEW, the son of a Russian merchant, was born in London, in February, 1819. He was educated at a private school at Clapham, and in the year 1840 he entered, as a pupil, the engineering establishment of Messrs. John Penn and Son, of Greenwich. His natural aptitude for mechanical pursuits finding there a favourable field of exercise, he steadily advanced to high proficiency in the more scientific departments of his profession. He filled for some years the position of Chief Draughtsman, and on the 1st January, 1847, he became a partner in the firm—taking a very active and intelligent part in the management of the works. In this position the designing and the general superintendence of constructing the great marine engines emanating from that celebrated manufactory, to a considerable extent, devolved upon him.

The number of these marine engines and, in some cases, their stupendous proportions, the position in respect of excellence which they so deservedly held, the reputation for pre-eminence in regard to rapid and economical transport which they have helped to confer upon the British navy, and the high appreciation in which they have been and are held in the navies of other countries, render it easier to do justice in thought than in word to the skill and ingenuity—called for in every grand feature of design and all the minutiæ of workmanship—on the part of those who were concerned in the direction of their manufacture.

Mr. Matthew was eminently fitted for the position he filled; he had a keen perception and a clear mind; and although his character was decisive, his sociability and good-fellowship caused him to be a favourite with all who knew him. As a skilful draughtsman and a dexterous workman he could in turn instruct the student at the drawing board, the turner at the lathe, the artificer at the bench; and from each he could educe excellence by example. Handiwork to him was recreation: he had a well equipped workshop at his private residence, where on a fine lathe, by Holtzapffel, fitted with a geometric chuck and all appliances, it was his delight to execute elegant examples of engine turning.

Scientific amusements alternated, in his leisure, with mechanical pursuits. He possessed a varied collection of astronomical, meteorological, and philosophical instruments. At his residence in Greenwich he had a small but good equatorial telescope mounted in a dome upon the house-top. At his country seat at Box Hill, where he resided at intervals for about twelve years before his death, he set up a reflecting telescope; and at his subsequent residence in Park Lane, London, he had a small observatory, containing a transit and other instruments. He pursued science, however, rather for the pleasure it gave him in following the doings of others than with the idea of advancing it by researches or observations of his own making; indeed the occupations of his busy life would have left him small opportunity for so doing if the inclination had existed.

He was an enthusiastic amateur fireman, and upon every convenient occasion donned the uniform of the Metropolitan Fire Brigade, and gave assistance to the officers of that service, often at considerable sacrifice of personal comfort, and not unfrequently incurring personal danger. He had a small museum of objects more or less curiously damaged by heat and water, which he had recovered from the numerous fires at which he had assisted.

Success, professional and material, attended Mr. Matthew's connexion with the firm of Messrs. John Penn and Son, and in the year 1867 he retired from business with fair hopes of long and

healthfully enjoying the fruits of his prosperous labour. In July, 1868, however, but one year after his relief from business avocations, an indisposition came upon him which gradually assumed a serious aspect. His mind became weakened and eventually collapsed; and he died on the 7th of August, 1869.

Mr. Matthew was fond of attending the meetings of scientific societies. He was a Fellow of the Meteorological Society, and of the Royal Microscopical Society. He was elected a Member of the Institution of Civil Engineers on the 3rd of April, 1849. He frequently attended the meetings, taking great interest in the proceedings, but he could not be persuaded to impart, in the discussions, the stores of knowledge which he possessed. He was a very worthy good man, and a firm friend, and he will deservedly live in the recollection of all who knew him.

Mr. WILLIAM CHADWELL MYLNE,[1] F.R.S., the son of Mr. Robert Mylne, F.R.S., the architect of old Blackfriars bridge, was born in London on the 6th of April, 1781. He was the hereditary representative of at least eight consecutive generations, commencing in Scotland towards the close of the sixteenth century, who have followed the same calling. Of his youth and early education it has not been very clearly ascertained beyond a suggestion that he had not at first been intended either for the engineering, or the architectural profession, in consequence of his elder brother having been destined for it, who eventually entered the Navy and died at an early age. He however had, from the nature of his father's works, early association with engineering. Thus, in 1797, he assisted with young Golborne to stake out the lands purchased for his father's great scheme of the Eau Brink Cut above Lynn, but which came to a standstill, from want of proper enterprise, until Rennie, in 1817, secured the necessary capital and executed the work. Subsequently he was occupied on his father's well-known project, the Gloucester and Berkeley ship canal, 70 feet of water surface. He succeeded his father as Engineer of the New River Company in the year 1811, having been previously appointed for three years assistant engineer. This gave the main bent to his career, and thenceforward his name is associated with the water supply of London. He was likewise extensively engaged in the supply of water to many important towns in the United Kingdom, and to some places on the Continent, carried out large drainage undertakings in the fen districts, designed and superintended the

[1] The publication of this notice has been deferred, in the hope and expectation that fuller particulars would be obtained, so as to allow of a more appropriate record being prepared. It is now printed, as a more complete account of the professional career of Mr. W. C. Mylne cannot be procured.—*Sec. Inst. C.E.*

erection of St. Mark's Church, Myddelton Square, as well as other buildings, and had a considerable practice as a surveyor and valuer, being for fifty years Surveyor to the Stationers' Company, and as a valuer he was employed by the Crown in connection with improvements in the Strand. At the date of his appointment by the New River Company the only water-works on the north side of the Thames were those of that company, the London Bridge Water-works, the York Buildings, and the Chelsea Company's Works. In his capacity as Engineer to the New River Company, one of his first undertakings was to substitute cast-iron pipes throughout their district, between Charing Cross and Bishopsgate Street, for the numerous wooden mains dating from Sir Hugh Myddelton's time, which were found insufficient to stand the requisite pressure, and to erect steam-engines for raising the water to a higher level than the Clerkenwell reservoirs. These several works are said to have cost a quarter of a million sterling. In consequence of the purchase by the Company of the water-works connected with old London Bridge and the York Buildings, a powerful steam-engine was, by the terms of the agreement, erected at Broken Wharf, Thames Street, to take water from the Thames in case of accident to the New River. This was used only occasionally, during extreme drought or frost, and has since been wholly removed. The cast-iron suction main was 33 inches in diameter, which was then considered a large size. About the year 1828, he constructed fifty acres of settling reservoirs at Stoke Newington, with a steam-engine for raising the water to a higher level, for the better supply of the upper and outlying districts on the northern side of the metropolis. In 1850 he gave evidence before the Metropolitan Sanitary Commission of the General Board of Health, on the supply of water to the metropolis. He had then been in office about forty years. His evidence showed that he was favourable to the use of 4-inch tubular drains, and of 6-inch or 9-inch branch sewers with proper inclination, and also to the abandonment of cisterns and tanks, and the resort to the constant supply for dwellings of the lower classes,—but for those only,—and he appeared to be aware of the difficulty of carrying out an entire change in connection with the then existing arrangements of the Company.

In later years the introduction of new water companies to meet the rapid growth of the metropolis led to many parliamentary struggles, in which Mr. Mylne took a prominent part. In compliance with "The Metropolis Water-works Act, 1852," the reservoirs at the New River-head were converted into filter-beds, whence the lower districts are supplied. The reservoir in Claremont Square was deepened, and arched over to prevent the water from being affected by the atmosphere and the London soot, and the

water is raised by pumping into this reservoir, together with a large proportion from the Stoke Newington reservoirs, from which the upper districts are supplied. Other covered reservoirs were erected about the same time at Highgate and Hampstead, into which the water was pumped by steam power. Extensive filter-beds were constructed at Stoke Newington, in connection with a large pumping establishment, whereby the upper districts of the metropolis are now supplied with filtered water. Filtering-beds were also constructed at Hornsey; and the New River was shortened several miles, by cutting off much of its circuitous course, whilst the remaining portions of it were deepened, widened and improved, to the spring-head at Chadwell, near Ware. The connection with the river Lee was altered, so as to yield a larger supply of water than formerly; and the drainage of the town of Hertford, above the source from whence the supply from the river Lee was taken, was removed, and thus prevented from contaminating that part of the stream. The adoption of these modern improvements of filtration, covered reservoirs, and more powerful machinery, rendered necessary by the Act before referred to, are said to have cost the company nearly three quarters of a million sterling.

During the period of his association with the New River Company Mr. Mylne was engaged in numerous works unconnected with the company, and he furnished many able reports. These related to drainage, docks, and water supply. He was much engaged in giving evidence in railway parliamentary contests, particularly on the details of cost of construction. In the Fen district he was much occupied. He carried into effect works for the improvement of the river Ouze, between Littleport and Ely, and others on the river Cam, and the drainage of Burnt Fen and the country adjacent. He reported on other various works respecting the south level of the Fens. Amongst his reports were one on Lynn Harbour, one on the banks of the river Ouze below Denver Sluice, and one (dated 1825, in conjunction with the late Mr. James Walker, Past President Inst. C.E.) "in consequence of the late intended Eau Brink Act," addressed to the Corporation of the Bedford Level and the Commissioners of Eau Brink Drainage.

Amongst his works was the intercepting drain at Bristol, by which the sewage was removed from the floating harbour. He made designs for the suspension bridge at Clifton, and also for piers at Portishead at the mouth of the Avon, for the mail-packets. His reports include several on proposed docks, as at Birkenhead, and also on the encroachments of the Mersey and other rivers; and from his position and reputation, his evidence was frequently sought by commissions and parliamentary committees.

In 1847 Mr. Mylne and Mr. H. B. Gunning, as "surveying officers" under the "Act for making preliminary Inquiries in

certain Cases of Application for Local Acts," conducted several inquiries, and reported to the Commissioners of Woods and Forests on the Leeds Water-works Bill and the Leeds and Thirsk Water-works Bill, on the Rochdale Water-works Act Amendment Bill, on a bill for Darwen, Derby, and other proposals. Mr. Mylne was consulted upon the Glasgow old Water-works; and for Birmingham he gave a detailed report with estimate. There was also a project for the supply of water for Paris in 1815, with which Professor Donaldson was associated; and subsequently there was another project in 1836.

As surveyor to the New River Company, he laid out their property, near Islington, for the streets and buildings, which have been since carried out as he proposed. For the University of Cambridge, he designed and superintended the erection of Gerrard's Hostel Bridge over the river Cam. It was a single-arched iron bridge, erected by the Butterley Company. Illustrations of it (Plates 95, 96, and 97) will be found in Hann and Hosking's "Theory, Practice, and Architecture of Bridges" (Weale, London, 1843).

Mr. Mylne was for upwards of fifty years a member of, and for many years Treasurer of the Smeatonian Society of Civil Engineers. He was elected a Member of the Institution of Civil Engineers on the 28th of June, 1842, and he served on the Council for five years, from 1844 to 1848, both inclusive. He was elected a Fellow of the Royal Society on the 16th of March, 1826, and he was likewise a Fellow of the Royal Institute of British Architects, and of the Royal Astronomical Society. His retiring disposition caused him seldom to take part in scientific discussions; but he took a keen interest in all questions of progress, and during his long career judiciously availed himself of the opportunities afforded him of adopting the new inventions of the age.

He had retired from professional life for two or three years before his death, which occurred at his residence, Great Amwell, Herts, on Christmas Day, 1863, in the eighty-third year of his age. His genial habits, kindly feelings, and strict integrity, won for him the esteem of his professional brethren, and the respect of all associated with him, not excepting the artisan, whose interests he at all times appreciated and considered.

Mr. JAMES BEAUMONT NEILSON, the inventor of the system of the application of Hot Blast to Iron Furnaces, was born on the 22nd of June, 1792, at Shettleston, near Glasgow. His father was an engineer, or what at that time was called an "engine-wright." Beaumont, as he was usually named, was the younger of two sons. John, some years his senior, received a classical education; but, instead of going into the Church, he

adopted the profession or trade of his father, and at his works, in 1825, designed, and afterwards constructed, an iron steamer which, following the 'Aaron Manby,' built in 1820, was among the early iron vessels that went to sea. Beaumont, while still a youth, assisted his father in erecting and working steam-engines employed for mining purposes, and was subsequently an apprentice in his brother's works. In 1814 he obtained a situation as engine-wright at a colliery in Ayrshire, and in 1817 was appointed Engineer of the gas-works then being established in Glasgow. During the time he retained the position of Engineer and Manager to the Gas Company, which he resigned in 1837, the Company's works were greatly extended, and Mr. Neilson introduced many improvements in the manufacture of gas, rising to great eminence as a gas engineer. He substituted clay for iron in the construction of the retorts, heated the retort ovens, as early as 1826, entirely with the waste coal tar employed as liquid fuel, and introduced the use of sulphate of iron solutions to remove the ammonia from coal gas in the process of purifying. Although not one of the most important, yet probably the most ingenious of his inventions in gas engineering was the swallow-tail burner, now in universal use. He was also amongst the first who constructed large roofs entirely of iron. Mr. Neilson had his attention drawn to the circumstance of the irregularity of the action of blast furnaces, more particularly the difference between the working of the same furnace in summer and in winter. Having been consulted by an iron-maker as to the practicability of submitting the air-blast to some chemical purifying process, he at first thought that the air ought to be freed from moisture, and the action of the oxygen increased in the furnace. He then commenced a series of experiments, the result of which was the Hot Blast Patent, dated 1st October, 1828. The title of the patent was written by the late Lord Brougham. Not having either the pecuniary means or the influence necessary to induce the iron-makers to adopt his invention, Mr. Neilson gave three-tenths of the patent to his friend and adviser, Mr. Charles Macintosh—the well-known manufacturer of water-proof cloth—three-tenths to Mr. Colin Dunlop, of the Clyde Iron-works, and one-tenth to Mr. John Wilson, of the Dundyvan Iron-works, retaining only three-tenths for himself. Iron-makers were originally much prejudiced against the invention, it being generally considered that the colder the blast-air could be made the better—refrigerators, even with ice, having in some cases been tried. After meeting many obstacles, and overcoming many difficulties, the patentees succeeded in having their invention tried. Every trial was a success, and in a few years the Hot Blast system became generally adopted by all the iron-makers in Scotland. A clear saving of thirty-two shillings per ton of pig-iron made, as com-

pared with the old cold-blast system, was obtained, and the quantity of iron produced by each furnace was doubled. Notwithstanding, the troubles of the patentees continued; for although only one shilling per ton royalty was demanded, the iron-masters in Scotland set about to attempt to destroy Mr. Neilson's patent. This, however, was vigorously and successfully defended. But in 1840 a confederation was secretly formed by a number of the wealthy iron-masters, who bound themselves under a formal deed "To institute, defend, carry on, and follow out to a conclusion, such actions, and generally to adopt such proceedings, judicial and extra-judicial, as their advocates, or the survivors of them, shall advise to be expedient and proper for setting aside the said letters patent, and for resisting the enforcement of the claims founded by the said James Beaumont Neilson, &c." The struggle between the patentees and the confederate iron-masters continued from 1839 to 1844. Twice a jury refused to deprive Mr. Neilson of his rights. Twice were appeals to the House of Lords unsuccessful. Two jury trials occupied sixteen days, and about one hundred and forty witnesses were examined. At one and the same time, twenty different actions were carried on, and the litigants spent between them, on law charges alone, not less than £40,000. Mr. Neilson was much discouraged, but the firmness and determination of his co-patentees carried him through his difficulties, and he realized a moderate fortune. It has been estimated that this country has been benefited by this invention to the extent of about twelve millions sterling per annum, and that an impetus was thus given to those great works in which cheapness and abundance of iron are necessary.

Mr. James Beaumont Neilson was elected a Member of the Institution of Civil Engineers on the 29th of May, 1832, whilst he was Engineer and Manager of the Glasgow Gas-works, and he died at his residence, Queenshill, Kirkcudbrightshire, on the 18th of January, 1865, in the seventy-third year of his age.

Mr. HENRY O'HAGAN was born in the year 1819, near Ballymena, in the county of Antrim, where his father was a small landowner. After receiving such instruction as could then be obtained in some of the small country schools, he, at an early age, obtained employment on the Ordnance Survey of Ireland, under Captain Henderson, R.E., who was very partial to him, and by whom he was engaged in making trigonometrical calculations, for which he had a remarkable aptitude, and in drawing. When the Tithe Commission Survey was being carried out, under the direction of the late Colonel Dawson, R.E. (Assoc. Inst. C.E.), Mr. O'Hagan came to England, about the year 1839, and was occupied

under Mr. A. Doull (Assoc. Inst. C.E.) for a considerable time in the execution of several parish surveys, and subsequently on railway surveys, in the conduct of which he was invariably found to be most zealous and trustworthy. The railway surveys herein referred to were for projected lines in Kent, to which Mr. Vignoles (Pres. Inst. C.E.) was the Engineer-in-chief. It was in this way that Mr. O'Hagan first became known, about the year 1844, to Mr. Vignoles, to whom he was afterwards an assistant, both in the office and on works. From 1846 to 1853 he had charge, as Resident Engineer, of the construction of important works on the Blackburn railway, under the late Mr. Flanagan (M. Inst. C.E.), and he resided during those years at Blackburn. On the 4th of May, 1852, he was elected an Associate of the Institution of Civil Engineers. He then acted as Resident Engineer for two years on the West Swiss railways; and from 1858 to 1864 had charge of the construction of a portion of the Tudela and Bilbao railway, to which Mr. Vignoles (Pres. Inst. C.E.) was the Engineer-in-chief, and Mr. Henry Vignoles (M. Inst. C.E.) was the acting Engineer. After the completion of the railway, he was for some time intrusted with the maintenance of the way and works on a length of ninety miles of the line. On the 10th of May, 1864, he was transferred from the class of Associates to the class of Members in the Institution. He was also variously employed at intervals on other engineering projects in Europe and America. Subsequently he was connected with the execution of the works on the Bahia railway, for Mr. John Watson (M. Inst. C.E.), the contractor; and in the latter part of 1868 was induced to accept an appointment under Messrs. Waring Brothers and Mr. M'Candlish, the contractors for the execution of the Honduras railway. He sailed for that destination on the 2nd of December in that year; but soon after his arrival he was seized with a fatal illness, due, it is asserted, to the hardships inseparable from the prosecution of the works, and died on the 7th of March, 1869.

Mr. O'Hagan occupied a respectable position in the profession, and was highly honourable in all the relations of life. It deserves to be recorded, to his credit, that he was almost entirely self-educated. He was a great reader, possessed a very retentive memory, had the gift of acquiring foreign languages with facility, and the capability of readily using and applying the knowledge he acquired. Amusing and entertaining in conversation, no subject came amiss to him; and while he had many friends, he is believed never to have made an enemy. He had a ready way of imparting information to others; and he took a delight in endeavouring to make the younger members of the profession fully understand any work upon which they might be engaged under him.

Mr. JOHN SHAE PERRING was born on the 24th of January, 1813, at Boston, Lincolnshire. He was educated at the Grammar School at Donington, and was articled on the 28th of March, 1826, to Mr. Robert Reynolds, the Surveyor of the Port of Boston, under whom he was engaged in surveying, in the enclosure and drainage of the Fens, in the improvements of Boston Harbour and of Wainfleet Haven, and the outfall of the East Fen, in the drainage of the Burgh and Croft Marshes, and other works. In 1833 he left for London, and was there employed in a variety of subordinate positions in different engineering establishments. In March, 1836, he went to Egypt, under contract with Messrs. Galloway Brothers, of London, as Assistant Engineer to Galloway Bey, then engaged on public works for H.H. Mohamed Ali, Viceroy of Egypt. One of the first works upon which Mr. Perring was engaged was the construction of a tramway, or small railway, from the quarries near Mex to the sea. After the death of Galloway Bey Mr. Perring was employed on several public works in Egypt. He became a member of the Board of Public Works, was consulted as to the embankment of the Nile, advocated the establishment of stations in the Desert between Cairo and Suez, to facilitate the overland transit, and was employed to make a road with the object of carrying out these views. He examined the Red Sea and the ports in connection with the overland route, and, in conjunction with Colonel Howard Vyse, carefully explored the Pyramids. The results of his labours in this exploration are published in a large folio work called the "Pyramids of Egypt," being the first in which authentic details and measurements of these structures were given. The value of his researches in this field are fully acknowledged in Bunsen's great work on Egypt, and the equally elaborate book issued by the Prussian Government. After visiting Upper Egypt and Nubia, and becoming thoroughly acquainted with that country, he returned to England in June, 1840, spending several months in Italy when travelling homewards. On the 1st of March, 1841, he entered upon the duties of Engineering Superintendent of the Llanelly railway, the Docks, and Harbour, and advocated a railway through South Wales, besides several local improvements. He did not, however, remain long in that position, for in the latter part of 1843 and the beginning of 1844 he resided in Paris. In April, 1844, he became connected with the Manchester, Bury, and Rossendale railway, of which Mr. C. E. Cawley, M.P. (M. Inst. C.E.), was the Engineer. This he carried to a conclusion under the superintendence of Mr. T. L. Gooch (M. Inst. C.E.), and on its amalgamation with other lines, became, in 1846, the Resident Engineer of the East Lancashire railway, of which the Manchester, Bury, and Rossendale, formed part. He continued to be the Engineer of that Company

until its amalgamation with the Lancashire and Yorkshire in 1859.

He was elected a Member of the Institution of Civil Engineers on the 6th of December, 1853, at which date he had been for seven years the Resident Engineer of the East Lancashire railway. He was subsequently connected with the Railway Steel and Plant Company, and was Engineer of the Ribblesdale railway, and constructed the joint lines from Wigan to Blackburn, as well as being the Engineer of the Oswaldtwistle and other waterworks. At the time of his death, which occurred on the 16th of January, 1869, from an apoplectic seizure, when in the fifty-sixth year of his age, Mr. Perring was the Engineer of the Manchester City railways in conjunction with Mr. W. W. Hulse (M. Inst. C.E.), and was advocating the construction of a railway under the river Mersey, having for its object the connection of the ports of Liverpool and Birkenhead. His friends had the highest esteem and respect for him as one who laboured honestly for the benefit of mankind to the best of his powers.

Mr. NEIL ROBSON, son of Mr. Robert Robson, was born in the district of Galloway in 1807. He was educated at the Irvine Academy, and at the age of seventeen was articled to Mr. T. Smith, of Glasgow, with whom he remained for a short time after the expiration of his pupilage. In 1833 he commenced practice as a Civil and Mining Engineer in Glasgow, and he always held a leading position in the profession. His name is associated with most of the large engineering works in the west of Scotland, several of which he constructed, including the line of railway between Gartsherrie and Whifflet, now a portion of the main line of the Caledonian railway, the Glasgow, Burrhead and Neilston railway, the General Terminus railway, the Caledonian and Dumbartonshire railway, the Glasgow and Helensburgh railway, and the Lesmahagow railway. He was largely employed as a Mining Engineer, and was looked up to as a leading authority in that branch of the profession. During the last few years of his life, he had the management of the extensive iron and coal works of Messrs. Merry and Cuninghame, of which firm he was a partner. He also held the position of deputy-governor of the Forth and Clyde canal, the most important work of the kind in Scotland, and he was a director in several railway companies. In 1838 he married Miss Agnes Merry, daughter of the late Mr. James Merry. Mr. Robson's last illness was of short duration, and he died on the 1st of February, 1869, in the sixty-second year of his age.

Mr. Robson was elected a Member of the Institution of Civil Engineers on the 6th of May, 1845. He was one of the originators and a Member of the Institution of Engineers in Scotland,

and was elected its President, but, owing to his many duties, had to decline the office. He was also a Member of the North of England Institute of Mining Engineers, and of the Philosophical Society of Glasgow. He was highly esteemed for his strict integrity, and in him the profession has lost a valuable Member. In private life he was noted for kindliness of heart and for his generosity, and he leaves a large circle of friends to regret his loss.

MR. JAMES SIMPSON, the fourth son of Mr. Thomas Simpson, the Engineer of the old Chelsea waterworks, formerly situated on the banks of the Thames, near to the present Victoria railway bridge, was born on the 25th of July, 1799, at the engineer's residence on those works, and received there his first instruction in the profession of a civil engineer. At the death of his father, in 1823, Mr. Simpson was appointed Engineer to the Company. Amongst his earliest achievements must be mentioned that of the filtration of water on a large scale. About the year 1827 he was instructed by his Company to investigate that subject, and after examining into the previous efforts that had been made to purify water, which had been chiefly done for manufacturing purposes, he designed and executed, in 1828, at the Chelsea waterworks his first "filter bed," which had an area of about one acre, and which was so successful, that no material alteration has been made in the system of filtration since that time: similar filters being now in operation in almost every town artificially supplied with water.

The elder Simpson had, in the year 1785, assisted in establishing a small company for the supply of portions of Southwark and Vauxhall with water, and had erected pumping-engines on the south side of the Thames near the present Charing Cross Bridge. To the management of these works his son also succeeded as Engineer, and the present high position of the Lambeth Waterworks Company is mainly due to the talent and energy displayed by Mr. James Simpson. The construction of elevated reservoirs at Streatham and at Brixton, with the iron mains and pumping-engines in connection with them, were amongst the earlier works performed, and the then operations of the company were hastened by the rapid spread of population in that district, as well as by the competition of the present Southwark and Vauxhall Water Company, which occupied at that time much of the same district, both companies striving to outstrip each other in extension of territory. This competition was closed about 1840, by arrangement between them, and the spread of the Lambeth works was rapid down to the year 1849, when, owing to the greatly increasing deterioration of the Thames water in and near London,

Mr. Simpson advised his company to take the bold step of removing the works to their present position at Seething Wells, between Thames Ditton and Kingston. The extensive filter beds and pumping station, constructed there in 1850, were the first which were designed for taking Thames water above tidal influence, and embrace, amongst other engineering features, the longest line of pumping main perhaps ever attempted, at all events until that period. The success of the first removal of the Lambeth works, followed by the public agitation on the subject of the metropolitan water supply, resulted in the passing of a general Act in 1852, obliging all the companies to remove their works above tidal flow. In the following year Mr. Simpson induced the Chelsea Water Company to select a locality above Kingston adjoining the Lambeth works, and accordingly, by an Act obtained in 1853, the present extensive works of the former company were constructed, and were opened in 1856.

Early in life Mr. Simpson became the engineering adviser of the Government on many subjects. He constructed waterworks for the supply of Windsor Castle during the reign of his Majesty George IV., and in succeeding years he was more or less constantly engaged in designing or conducting water supplies to the royal palaces, as well as being consulted on various sanitary works in connection therewith, and he was thus to the period of his decease engaged in the service of the department of works, either as civil engineer designing works, or giving advice, or as a manufacturing engineer, constructing machinery for the Board of Works at his extensive works in Pimlico.

During his long career, Mr. Simpson was also extensively engaged on various large engineering works in different parts of the country. In 1842 he designed, and afterwards carried out, the long pier at Southend for landing from steamers at low water; and in the year 1843, Mr. Ralph Ward Jackson, M.P. (Assoc. Inst. C.E.), having conceived the idea of a wet dock there, as a rival to the old Hartlepool Harbour, sought Mr. Simpson's advice upon the subject, the result being that an Act of Parliament was obtained, and a dock and harbour, with other works, constructed; the nucleus of the present extensive town and port of West Hartlepool, which now ranks amongst the largest shipping ports for coal in the kingdom.

About the year 1845 Mr. Simpson was consulted by a new company formed at Bristol for the supply of water, and he designed the extensive works for bringing to that city springs and streams of water from the Mendip Hills. These works embrace all the features of a large undertaking of the kind, and have been completely successful, both in an engineering and commercial sense. The sanatory requirements and measures of the period opened a

great field for private enterprise, in the formation of companies and the construction of waterworks, in every town of any importance in the kingdom. Mr. Simpson being a leading authority, soon became extensively engaged in such works, and he constructed or improved works at many of the most important towns in this country, amongst which may be mentioned Newcastle, Liverpool, Manchester, York, Cardiff, Reading, Cambridge, Carlisle, Exeter, Folkestone, and Gravesend. He was also consulted, about the year 1856, as to water and gas works at Copenhagen, and afterwards designed and carried out, as consulting engineer, the present extensive works there. The town of Aberdeen likewise owes to him the design and execution of the very comprehensive and complete works for supplying that town with water, taken from the river Dee, about twenty miles above the city. Of several of his works Mr. Simpson contributed accounts to the Institution, and some of them are published in the Transactions and the Minutes of Proceedings.

Although Mr. Simpson's engineering talents were principally directed to hydraulic works, he was consulted on and was connected with many minor engineering works and enterprises, and took part in all the parliamentary campaigns of the last twenty-five or thirty years, as adviser, promoter, or opponent of companies and other bodies. He was thus intimately associated with all the leading members, not only of the present, but of the past generation of engineers; being in early life the friend and associate of Telford, Rennie, Mylne, the Bramahs—father and sons, Maudslay, Donkin, Field, Walker, Manby, of the older names, and with the leading engineers and scientific men of his own time, with all of whom he was more or less intimate, and in the habit of acting in his profession, and with whom his name will be classed and remembered.

As an engineer, Mr. Simpson took a large and comprehensive grasp of his case rather than of the minor parts and details; and accordingly his views were large and extensive, and habitually embraced a consideration of the results of his projects. He was not brilliant as a witness, nor as a speaker, but his advocacy generally carried great weight with it, and his opinions were held in high esteem, not alone because of the soundness of his views, but of his known and admitted honesty and uprightness of character. Being long the intimate adviser of many clients and interests, his policy, perhaps, led him to act more as an arbitrator than an advocate; while the suavity of his manner and the kindly geniality of his nature were influential in softening down professional asperities or in arranging disputes between rival parties, many of whom will remember these estimable qualities in looking back upon his long and useful career, extending over nearly half a century.

Mr. Simpson was elected a Member of the Institution of Civil Engineers in 1825, the same year in which Mr. Telford accepted the office of President. He was a Member of the Council from 1826 to 1844, a Vice-President from 1844 to 1853, and the President in 1854 and 1855. He at a very early period took an interest in the Institution, and during the whole of his long career was one of its warmest supporters; he was assiduous in his attendance at the Council, and at the ordinary meetings; he selected the best officers to be found, devoted his time and his funds to its advancement, and there are few members who have been such solid benefactors to the Society as he was.

His decease occurred on the 4th of March, 1869, at his residence, Westfield Lodge, Kingston-on-Thames, and his remains were interred in the Brompton Cemetery, the funeral being attended by a large gathering of the Council and Officers of the Institution, of his professional colleagues and other friends, besides the employés of the companies and of other undertakings with which he was connected.

Mr. WILLIAM GRÆME TOMKINS was born in the year 1817, at South Lambeth, Surrey. From 1833 to 1840 he served a pupilage under the late Mr. Bryan Donkin (V.P. Inst. C.E.), and on that gentleman's recommendation was, on the 10th of March, 1835, elected a Graduate of the Institution of Civil Engineers. In 1837 he accompanied Mr. Donkin's son to Italy, and helped to design some millwork for the Tyrol. Being found very intelligent, the firm retained him as an assistant from 1840 to 1843, when he was a good deal occupied in designing an iron mill for South Wales. From 1843 to 1853 he was engaged in Russia on his own account, in general practice, on various works—amongst others, the then Moscow Waterworks; and he was consulted as to the design and carrying out of paper mills in the neighbourhood of that city. He was employed, from 1853 to 1855, on the Great Western railway of Canada, as Resident Engineer on the Central division, and he afterwards remained in that country from 1855 to 1860, acting on his own account, during which time he was more particularly engaged in laying out and constructing roads, and was the Engineer to St. Mary's and Exeter, in the county of Perth, Canada West. After his return home, in 1860, he was connected with various professional works, but more especially at the Exchequer, for the Lords of the Treasury, in the subdivision of the standard instruments for the measurement of gas under the recent Act of Parliament. Latterly he had become interested in the manufacture of meters, and he had made a journey to St. Petersburg with a view to introduce a new kind of liquid meter, for measuring spirits, &c. On his way back, exposure to intense cold

brought on a serious illness, which terminated fatally on the 11th of January, 1868, in the fifty-first year of his age. He had only been transferred to the class of Members of the Institution on the 2nd of April, 1867, his repeated and long-continued absence in distant countries having led to his omission to make the application earlier.

Engineer-General ALEXANDER WILSON, of the Imperial Russian service, born in Edinburgh, on the 27th February, 1776, was the eldest son of James Wilson, smith, of that city. In his early years he attended first a grammar-school, and then the High School in the Canongate. He often regretted that his English education was interrupted by emigration of his family to Russia in 1784, where his father was employed by Mr. Cameron, architect to the Empress Catherine II., to superintend the iron-work of the building of the well-known Cameron Gallery in the Palace of Czarskoe Selo, near St. Petersburg. From May 1788 to 1790 he had the advantage of the instruction of a private tutor—the late Sir Robert Graham—who at one time laid claim to the baronetcy and estates of Netherby. This gentleman was engaged by Mr. Wilson, through the instrumentality of his wife's relatives in Scotland, to take charge of Alexander, and of the younger children, as well as of those of a limited number of their neighbours. During this period he also attended a Russian public school, and received some instruction in architectural and other branches of drawing, from a fellow-countryman, Mr. Hastie, while he also gave evidence of considerable facility in acquiring foreign languages. This school education terminated in his fourteenth year, but his love of learning continued through life, and on the failure of his eyesight, a few years before his death, he availed himself of the services of an efficient secretary to keep him well "read up"—his chief pleasure till within a few days of his death. From his early years he began to collect rare works on architecture and engineering, not neglecting general literature, and thus formed one of the largest private libraries in Russia, notwithstanding the loss of many rare and valuable works by fire in 1821. In the year 1790, his father having been transferred as master smith to the Government Small-Arms Manufactory at Sisterbeck, on the coast of Finland, Alexander was employed at the same place as draughtsman, at a small salary. Here he picked up a good deal of practical information, and in his leisure hours studied mathematics with a young officer of the surveyor's corps, who happened to be his nearest neighbour. In the year 1795 the father and son were at the same time promoted to the rank of officers in the Mining Corps. In 1800 Alexander was engaged as interpreter and secretary to General C. Gascoigne, who was then chief of

many of the imperial mechanical works. In 1803 his father and family left Sisterbeck for Colpino, about twenty miles from St. Petersburg, where Mr. Wilson was appointed resident director's assistant of the works under General Gascoigne. On the death of the latter, in 1806, Alexander Wilson, having displayed the requisite knowledge and business-like habits, was appointed to succeed him as director of the works at Colpino, and also at Alexandrovsk, on the banks of the Neva, nearer to St. Petersburg. At Colpino he had the honour of entertaining at tea, in his father's house, where he lived, the then reigning Empress of Russia, Elizabeth, wife of Alexander I., whose knowledge of English enabled her to converse with freedom in that language, and who was induced to visit the place by the special interest taken in the works under his care by the empress mother—Maria Fedorovna, widow of the Emperor Paul.

Then began the most active period of his life; and the variety of works, mechanical and architectural, planned and executed by him is indeed astonishing. At Colpino he reconstructed the old and constructed new sluices and waterwheels; introducing steam as an auxiliary to water power. He built several steamers, supplied them and others with marine engines, at a time when these things were novelties even in England. He planned the future town and supplied it with public schools and dwelling-houses for the workpeople, and lived to see a small village grow into a town of 8,000 inhabitants. At the Alexandrovsk works, also formerly a village and now a small town, the activity and genius of Alexander Wilson were no less successful. The original idea of establishing a manufactory at Alexandrovsk was due to the Empress Maria Fedorovna, wife of the Emperor Paul. Her aim was twofold; first, to educate and provide employment for the foundlings of the Imperial Foundling Hospital when of an age to be discharged from that establishment, and to make them skilful and experienced workmen, able to gain their own livelihood, and secondly, to prepare skilled artizans to carry their arts and knowledge of different manufacturing processes to the remotest parts of Russia. To accomplish this, General Alexander Wilson, being fully intrusted with the execution of the Empress's plans, built an immense institution for 800 boys and girls, provided with a library, schools, washhouses, &c., &c., at that time novelties in Russia. The order, cleanliness, and efficiency of this institution made it, as it was intended to be, a model of its kind. Besides this, General Wilson constructed extensive mills, containing all the improvements known at that time. The large flax mill at Alexandrovsk supplied sailcloth for all the Russian navy, when wind was the only motive power of men-of-war, besides furnishing a large quantity for general consumption both at home and abroad. Cotton mills, plain and figured weaving looms, mechanical works, and a manufactory

for playing cards, were all to be found at Alexandrovsk. In the card department he had the able assistance of a member of the Delarue family, who had the charge of it, and in the general superintendence of the establishments at Alexandrovsk, that of his brother, Mr. Lewis Wilson, until the death of the latter in 1847.

As an Architect, General Wilson appears to have possessed good taste, as is testified by the fine structures erected by him at Colpino, Alexandrovsk, and other places. While fulfilling his duties at Colpino and Alexandrovsk, he was, on many occasions, employed by successive sovereigns of Russia in undertakings not strictly connected with these places. He cast brass guns, coined copper money, improved anchors and chain cables, built churches and hospitals, and, after personal inspection, reported on the condition and management of different Russian ports, and engineering and mechanical establishments, viz., Archangel, Nicolaeff, Lougan, &c., and was acknowledged to be one of the most honest, trustworthy, and able servants in the Imperial Service. Besides these numerous government employments, he, with the permission of the crown, took an active part and interest in the planning and erection, and for many years in the management of two large cotton mills, among the original promoters of which were also the late Count Nesselrode and Baron Stieglitz.

Having passed through the inferior grades from his first appointment in 1795, and having been transferred in 1816 from the Corps of Mines to the Engineering and Building Department of the Admiralty, to which the establishment at Colpino is attached, Alexander Wilson was, for his many services, successively promoted, in 1818, to the rank of Major-General; in 1829, to that of Lieutenant-General; and in 1853, to his highest rank, that of Engineer-General. From 1820 to 1856 he was decorated with four Stars of different Russian Orders, the last being that in diamonds of St. Alexander Nevsky, when, by the special order of the Emperor Alexander II., a gold medal was struck, and presented to him, with a rescript from his Majesty, to signalize the completion of the fiftieth year of his direction of the Imperial Manufactory of Alexandrovsk, and of the Admiralty Ijora (Colpino) Works, and of the sixty-second year of his service in the empire.

General Wilson during his eighty-two years' residence in Russia paid ten visits to England; the first in 1814, during the visit of the Emperor Alexander I., whom he had the honour of attending in many of his inspections of public establishments in this country, and the last in 1862, to the International Exhibition—each time returning home well stored with new improvements and inventions in engineering, mechanics, and manufactures, purposing to apply the best of them in his adopted country. During his visits to England and other countries he had numerous opportunities of

being introduced to the greatest engineering, mechanical, and scientific celebrities of the day, with many of whom he was on a friendly footing, as Telford, the Rennies — father and sons,— Bramah, the Brunels—father and son,—the Stephensons—father and son, the Fairbairns, Manby, Walker, Simpson, Field, and others, with many of whom he kept up an active correspondence. Nor was he unmindful of those younger members of his profession "as yet to fortune and to fame unknown," whose careers were but commencing; and many such, now in positions of comfort and even opulence, gratefully remember the kind and ready interest shown by him in their early struggles. Having served Russia under five successive sovereigns, Catherine II., Paul, Alexander I., Nicholas, and Alexander II., to all of whom he was personally known, General Wilson retired from active service in 1860, enjoying a full pension from the Imperial Crown, and, by the special order of the Emperor, the use of the official residence at Alexandrovsk, which he had occupied since 1821, and in which he died, after a very few days' confinement to his bed, the 13th-25th February, 1866, within two days of completing his ninetieth year. Full of years and honours, he finished his active and useful life, esteemed and regretted by all who knew him, more especially by those over whom he had presided for so many years, with ever ready and kind consideration of their wants and representations. The affectionate esteem with which he was regarded by these people will be seen from the following extract of a letter from St. Petersburg, describing his funeral procession; the service having been performed in the chapel of the British Factory at St. Petersburg, to which no cemetery is attached. He was buried in the family grave at Colpino.

"At every village through which the procession passed the clergy and poor turned out, and insisted on carrying the body; the old, grey-headed men struggling to be first. The arrival at Colpino was a perfect ovation. The St. Nicholas church there has a splendid choir; and their chanting and that of the clergy was most solemn and beautiful. Many were in tears; each full of what the General had done for them and their fathers during the fifty years when he was their chief; each had some tale to tell. It appears that when in office at Colpino he was in the habit of lending them money when they needed it—to build a house, or buy a cow—their wages being small; to some 50 roubles and upwards, to be repaid in small sums quarterly. The people have not forgotten this, or his many other acts of kindness and generosity. He has endowed two schools there; one for fifty girls, which was always full; another for boys, not so well attended."

To these traits of his character, may be added his untiring energy and industry, and his moderate and unostentatious mode of living; indulging himself in only one expensive luxury—the collection of a large and valuable library of rare and useful books. The following extract from the 'Times' of the 25th June, 1854,

will be further evidence of the influence which he possessed with the Government:—

"From the millwright and other engineering departments at Colpino the Englishmen had less difficulty in obtaining their passports, owing to the mediation of General Alexander Wilson, a native of Scotland, who is at the head of that establishment, and who has spent the greater part of a long life (being now nearly eighty years old) in the Russian service, and who is an immense favourite with the Emperor Nicholas. The estimation in which General Wilson is held by the Emperor may be judged from the following incident, which occurred at Colpino, which is the first station on the railway between St. Petersburg and Moscow. On the occasion of the Emperor's visit to the latter city some time since, the General waited on his Majesty at the station, when the Emperor embraced him, kissed him on the cheek, and declared aloud he was the most honest man in his service."

General Wilson died unmarried, but left nephews and grand-nephews to preserve his name in Russia. He was elected a Corresponding Member of the Institution of Civil Engineers on the 16th of March, 1824—on the nomination of Mr. Telford, Sir M. I. Brunel, Mr. Field, and Mr. Jacob Perkins—and was removed to the class of Members on the suppression of the former class. During his periodical visits to Great Britain he invariably found time to visit the Institution, made minute and careful inquiries as to the progress of engineering science and practice, availed himself to the uttermost of the advantages of the Institution, and corresponded frequently with the officers of the Society, when he required information on special points between his visits.

Mr. CHARLES CAPPER, the only son of the late Mr. Robert Capper, of Manchester, was born in that city in the year 1822, where he also received his education. He entered upon the active duties of life in the employment of Messrs. Pickford and Co., the carriers, for whom he ultimately became agent at Liverpool. About the year 1845 he left Messrs. Pickford's to join the Great Eastern (then the Eastern Counties) railway as goods Manager, in which position he proved so useful that he was speedily promoted to be Superintendent of the line. At the opening of the Victoria (London) Docks he was selected by the lessees—Messrs. Peto, Brassey, and Betts—specially on account of his commercial knowledge, to be the general Manager of that large undertaking, and the revolution he effected in dock management is still felt and recognized by all associated with such interests. Shortly after the amalgamation of the London Dock Companies, which was mainly promoted by Mr. Capper, he was unanimously elected the Chairman of the Southampton Docks Company, a position which he held until his decease, and in which his peculiar talents were conspicuously displayed. He was also the Deputy Chairman of

the East London Bank, the Chairman of the Dagenham Docks Company, and he was in Commission of Lieutenancy of the City of London. In 1859 he received a commission as Major-Commandant of the 5th Essex Volunteer Rifle Corps, was promoted to the Lieut.-Colonelcy of that corps and of the 2nd Essex Administrative Battalion, and finally to the Honorary Colonelcy of the 5th corps, which commission he held at the time of his death. In 1863 he became a candidate for the vacant aldermanic gown in Langbourn Ward, but was too late in the field to succeed. At the general election of 1865, Mr. Capper contested the borough of Sandwich, in the Conservative interest, against two members of the Whig Government, Lord Clarence Paget and Mr. Knatchbull-Hugessen. It could scarcely be expected that he should succeed against such important influence at the outset; but the popularity he there acquired, by his genial manners and sound knowledge, led to his return as Member for the borough when a vacancy occurred in the following spring, though not without a severe struggle.

He was elected an Associate of the Institution of Civil Engineers on the 6th of December, 1864, on account of his intimate connection with numerous works of public utility, and from his having been the Author of a treatise which was published in 1861, and has since gone through several editions, on "The Port and the Trade of London," acknowledged to be a text-book of commercial information. Mr. Capper died of exhaustion on the 21st of March, 1869, after a comparatively short illness, at his residence at Upton, Essex, to which parish he was a considerable benefactor. Much sympathy was expressed in City circles at his premature decease.

Mr. THOMAS LONG COLLEY, son of Mr. John Long Colley, of Plymouth, was born on the 18th of August, 1840. After serving a pupilage of five years under Mr. Richard Townsend (M. Inst. C.E.), superintending Civil Engineer of H.M. steam-yard at Keyham, and Resident Engineer of Plymouth breakwater, Mr. Colley was engaged for three years at the Keyham North Basin Extension Works, as Engineer for Mr. Jackson, the contractor, and in that capacity was employed in setting out the work, levelling, &c. His ability, especially in dock work, there manifested itself, and he subsequently acted in a similar position for the same contractor during the construction of the Exmouth docks, the works of which were completed under his supervision. He was then for between two and three years in private practice, principally occupied in connection with the supply of water to towns. He carried out the waterworks at Exmouth. His career, which bid fair to be so successful, was prematurely cut short by his untimely death on the

9th of July, 1868, at the early age of twenty-seven years, and within a few months after his election as an Associate of the Institution of Civil Engineers. He left a widow and two children.

Mr. FRANCIS GORDON DAVIS, the younger son of Henry Davis, M.D., of Putney, was born at Tenbury, Worcestershire, on the 7th of September, 1843. He received his early education at the Cathedral School of Hereford, and subsequently passed two years at Bergedorf, near Hamburg. On his return, in 1860, he entered as a matriculated student in the applied science department of King's College, London, where he especially devoted himself to mechanics and the arts of construction, obtaining, in the first year, the workshop prize. The subjects of geology and mineralogy likewise attracted his attention, and it was this turn of thought which led to his taking up the department of mining instead of mechanical or civil engineering, for which he was originally intended. In 1862 he became a student at the Royal School of Mines; and at the final examination of the session 1863-64 he was awarded the De la Beche medal and prize. Shortly afterwards he obtained an introduction to the mining firm of Messrs. John Taylor and Sons, and under their auspices he proceeded to the Wheal Friendship and other mines in Devonshire and Cornwall. In the following year he went to the lead mines in South Wales, where he remained for more than eighteen months, working with the captains and miners during the day, and making plans and drawings, and arranging specimens of the different ores during his leisure in the evenings. Soon after his return to London, in November, 1865, he obtained, through the Messrs. Taylor, an appointment for three years to the Gonnesa Mining Company at Iglesias, in the Island of Sardinia. During the first campaign (as the mining season is called) the important discovery of a rich Calamine ore was made, which added greatly to the work devolving on him. His health, however, remained good till nearly the end of his engagement, when he experienced a mild attack of the ague fever, which prevails in the island. After several months his health was so much enfeebled that he returned to England to recruit, but by the beginning of October, 1868, he was able to resume his work. On his way to Sardinia he was occupied for a short time on a mining survey in the Vallée d'Aosta, near the foot of Mont Blanc, and did not arrive at Iglesias till the end of November. A few weeks afterwards, whilst on a surveying expedition in the island, he was again struck down with another and far more serious attack of malarial fever, but he succeeded in reaching Leghorn, and repaired to the hotel Washington, where he sank rapidly, and died two days after, on the 11th of February, 1869, in the 26th year of his age. His remains lie interred in

the British cemetery. During the time he was in Sardinia he contributed a Paper "On the mines of the Gonnesa Mining Company," which was read at the annual meeting of the Miners' Association of Cornwall and Devonshire, and published by them in 1866; and in the following year, 1867, he sent another short Paper, which was read and published by the Association, "On the Calamine deposits of the Island of Sardinia." Just before his last fatal illness he had commenced a Paper, intended for the Institution (to which he felt a pride in belonging), "On the Machinery for the Washing and Preparation of Lead Ores," a subject to which he had paid much attention, and which he hoped would have been thought worthy of a place in the transactions. Whatever his hands found to do, whether for himself or his employers, he always performed with a will; and although he was devoted to scientific pursuits, he became a skilled workman, and made his own models for the machinery he designed, as well as cabinets for his tools and mineralogical specimens. Mr. Davis was elected an Associate of the Institution on the 1st of December, 1868.

Captain FRANCIS FOWKE,[1] R.E., was born at Belfast, in July 1823. His early education was received at Dungannon College, but at the age of sixteen he was entered at the Royal Military Academy at Woolwich, and he obtained a Commission in the Royal Engineers in 1842. After being stationed for several years at Bermuda, he, on returning to this country, designed and made the working drawings for the Raglan barracks, at Devonport, in which, it is said, many comforts and facilities were provided not previously customary in similar buildings. In 1854 he received his captain's Commission, and in the same year undertook the charge of the machinery sent from Great Britain to the Paris Universal Exhibition of 1855, and was, at a somewhat later period, appointed secretary to the British Commission, and resided in Paris during the year of the Exhibition. In connection with that Exhibition he wrote two reports: one on "Civil Construction," and the other on "Naval Construction." He also conducted a series of valuable experiments on the strength of colonial woods, which, in the colony of Jamaica, had the effect, it is said, of increasing the annual export of lance-wood spars fourfold, and raising that of mahogany from 4,869 feet to 39,474 cubic feet.

In 1857, after the conclusion of the work in connection with the Paris Exhibition, he was made Inspector of the Science and Art Department, and subsequently he became the engineer and architect of the South Kensington Museum, and made many ad-

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[1] The "Professional Papers of the Corps of Royal Engineers," vol. xv., contains a notice of the career of this officer, from the pen of Mr. Henry Cole, C.B.

ditions to the iron building known as the "Boilers," which was designed by the late Sir William Cubitt (Past-President, Inst. C.E.), as a means of affording temporarily the greatest amount of covered space at the least cost. About this time Captain Fowke was called upon to design, in conjunction with Mr. Redgrave, R.A., a gallery for the exhibition of the pictures bequeathed to the nation by Mr. Sheepshanks; and the object sought to be attained, the possibility of seeing the pictures without glitter or reflection, has in most respects been accomplished. On this occasion he applied a novel principle to the lighting of picture galleries by gas: and, by the use of ingenious machinery, many thousand gas-burners are lighted every evening in a few minutes. The Vernon and the Turner Galleries of the South Kensington Museum were built by him, with fireproof floors, in the course of eight weeks, in December, 1858, at a cost, it is asserted, not exceeding 4*d*. a cubic foot. But Captain Fowke's greatest feat, in the economical use of materials, was in the construction of a drill-shed for the 1st Middlesex Engineer Volunteers, of which corps he was the founder. This shed was 100 feet in length by 40 feet in width, and consisted of semicircular ribs of timber resting on brick foundations and covered with felt. The cost of this to the corps did not exceed £100, but some of the members of the corps gave their labour gratuitously. A similar principle was adopted in the construction of the temporary entrances to the Horticultural Gardens; and numerous Volunteer corps throughout the country were provided with drill-sheds after the same design.

In 1858 Captain Fowke was appointed to represent England at the Paris Technical Commission, which was charged to give an opinion upon the plans proper for improving the entrance to the Danube from the sea, when the St. George's branch was unanimously recommended for adoption; but the works have not, from various reasons, been carried out according to the views then expressed.[1]

Captain Fowke likewise laid out the ground at South Kensington belonging to the Commissioners for the Exhibition of 1851, gave the first general plan for the Horticultural garden, which was subsequently modified by Mr. Nesfield, and designed the conservatory, regarded as one of the best constructions of the kind, as well as the south arcade, in which terra-cotta was introduced with good effect. In 1859–60, as architect of the Science and Art Department, he designed the New Industrial Museum at Edinburgh, the first stone of which was laid by the Prince Consort in October, 1861; and about the same time the interior of the National Gallery in Dublin was remodelled and added to by him. The

[1] *Vide* the "Professional Papers of the Corps of Royal Engineers," vol. xvi.

series of buildings for the International Exhibition of 1862 was designed by him; but so many alterations were made from time to time, that he ought not to be blamed for its deficiencies in an artistic point of view, while as regarded lighting, ventilation, and general convenience it was generally admitted to have been a great success. He devised the plans for the new buildings for the South Kensington Museum, with the aid of the late Mr. Godfrey Sykes, as decorative artist. and these, as modified and improved by the Author, and in which large use has been made of terra-cotta, were being carried out at the time of Captain Fowke's death.

Several minor works were produced by Captain Fowke, including a drawbridge, elongated shot for rifled ordnance, collapsing pontoons, a portable military fire-engine, a folding camera, and improved umbrella, a portable india-rubber bath, and a travelling scaffold. His friend and colleague, Mr. Cole, has expressed the following opinion as to his career:[1]

"I firmly believe that the arts of construction in this country have sustained a great loss by Captain Fowke's death. At this period, when Art is so transitional, and Science is making so many discoveries, and men's minds are seething with inventions; when the use of new materials is being constantly manifested, and the new adaptation of old materials is constantly entered upon, England has lost a man who felt the spirit of his age, and was daring enough to venture beyond the beaten path of conventionalism. Captain Fowke, to my mind, was solving the problem of the decorative use of iron, and, by appreciating the spirit both of the Gothic and the Renaissance architects, was on the threshold of introducing a novel style of architecture, when, alas! death, at the early age of forty-two years, has cut short his promising career."

Captain Fowke joined the Institution of Civil Engineers as an Associate on the 19th of May, 1863. His decease occurred somewhat suddenly, from the bursting of a blood-vessel, on the 4th of December, 1865; but he had been in declining health for some months previously.

Mr. JOHN HAMILTON was born at Glasgow on the 23rd of January, 1818. He was descended from a family of respectability in the west of Scotland. Soon after his birth, his father, Mr. William Hamilton, removed to Antwerp, where he established a mercantile house and carried on considerable operations. These were interrupted by the revolution which led to the separation of Belgium from Holland. For a time the family resided in Hamburg, but eventually returned to Belgium, where the subject of this memoir completed his education. At an early age he exhibited a decided predilection for mechanical pursuits, and had he been permitted to follow the bent of his inclination would have chosen the profession

[1] *Vide* "Journal of the Society of Arts," December 8, 1865, p. 60.

of an Engineer while still a youth. He was, however, placed with an eminent mercantile firm in Antwerp, and such was the confidence reposed in his ability that, at the age of eighteen, he was entrusted with the negotiation of important business in Denmark, Norway and Sweden, which countries he visited for the purpose, and acquitted himself with so much discretion that he was next sent on a similar errand to the United States by the well-known house, Messrs. Gower Nephews, of London. He married in the year 1841 a lady of fortune, to whom he had long been attached, and shortly afterwards settled near Liverpool, where he established an extensive business, and erected large zincing works, ultimately combining therewith construction works, and executing important contracts for iron roofs, telegraph work, steam-vessels, &c., in which his early mechanical tastes found full scope; more especially in designing telegraph posts which were widely adopted in India, as they, with his girder bridges, were well suited to the wants of that country. He further designed and built numerous stern-wheel steamers of very light draught, suited for inland navigation; and in particular for the Russian Government he built a number of steamers, now on the sea of Aral, and which have been mainly instrumental in the extension of the Russian power over the barbarous legions of Central Asia.

In 1860 Mr. Hamilton organized the 7th Lancashire Artillery Volunteer Corps, and took the command as Lieut.-Colonel. This corps was composed entirely of artizans and others in his employment, by whom he was at all times deservedly held in the greatest respect and esteem. As a Volunteer officer he was distinguished for the same zeal and energy which he carried into every other pursuit.

After a successful career of twenty years he purchased a property—Hilston Park, Monmouthshire—to which he retired with the intention of devoting the remainder of his life to country pursuits. But his health now began to fail, in consequence, it is believed, of a shock received by his system when he accidentally fell backwards, a depth of 40 feet, from the pier at New Brighton into the river Mersey. No danger was at the time apprehended, but bad symptoms eventually appeared, and after three years of constant and severe suffering, which he bore with great patience, cheered by the presence and care of his amiable wife, he died at Bournemouth, on the 20th of December, 1868. In person he was singularly attractive and of truly winning manners, but his wit and penetration were only to be fully appreciated by those who enjoyed his intimacy. Generous and considerate to all, he was in everything a true English gentleman.

Mr. Hamilton joined the Institution as an Associate in the year 1856; he was a frequent attendant at the Meetings, and always took interest in the proceedings.

Mr. WILLIAM JERRY WALKER HEATH, son of Mr. John Joseph Heath, of Birmingham, was born on the 13th of August, 1835. He was educated at the Proprietary School at Edgbaston, and as he showed a strong predilection for mechanical pursuits, he was articled in 1850 for five years to Messrs. Fox, Henderson, and Co., of the London Works, Birmingham. During the latter part of his pupilage he assisted in the operation of sinking the cylinders, by the pneumatic process, forming the foundation for the railway bridge over the Medway, at Rochester, and he was afterwards employed for one year, by the same firm, in the superintendence of railway works near Malmo, in Sweden. His next occupation carried him to Ceylon, where he had charge of the erection of buildings and machinery for Mr. G. F. Wilson, F.R.S., and from 1857 he was a general assistant in the drawing-office of the Ceylon Railway Company, under Mr. Doyne (M. Inst. C.E.) until the suspension of the works in 1860. During the two following years he was occupied in the construction of a railway bridge over the river Tagus, near Lisbon, for Messrs. Kennard. In 1863, when the works of the Ceylon railway were resumed by the Colonial Government, Mr. Heath received an appointment on the engineering staff as Second-class Assistant Engineer, and he remained until the completion of the line in 1867. Shortly after his return to England, he, in October, 1868, entered the Public Works Department of the Government of India as an Executive Engineer, and was put in charge of the Baroon division of the Soane circle in February, 1869. While occupied in laying out a canal from the river Soane, near Baroon, he received a sunstroke, which terminated fatally, after a few hours' illness, on the 29th May, 1869, in the thirty-fourth year of his age.

Mr. Heath displayed considerable constructive ability, and had a great love for his profession; while his unvarying good temper and kindly disposition endeared him to all who knew him. He was elected a Member of the Institution of Mechanical Engineers in 1862, and an Associate of the Institution of Civil Engineers on the 1st of December, 1863. He was also a Member of the Asiatic Literary Society.

Captain ANDREW HENDERSON, the son of Mr. John Henderson, of Shetland, was born at Liverpool on the 10th of January, 1800, and there received his education. He entered the Royal Navy in January, 1813, and was received on board the 'Princess' guard-ship, in the Mersey, whence, in the following year, he joined the sloop 'Bittern' as a midshipman, and was afterwards transferred to H.M.S. 'Bellerophon,' under Admiral Keats.

In July, 1816, he quitted the navy, and went to India with a free mariner's licence, and good letters of introduction from

Mr. Gladstone, in whose ship—the 'Liverpool'—he went out, which procured him employment under the firm of Palmer and Co., on board their ship 'General Palmer,' where he gained considerable experience. In 1821 he was their officer on board the 'Robarts,' bound for England. At Bencoolen the captain and all the other officers died, and Henderson barely survived. The command of the ship was given to him with the offer of taking her to England. This he declined, and took her back to Calcutta, as being more to the interest of the owners, who properly estimated his conduct; and thenceforth his character as a first-rate sailor and an honourable man was so firmly established that, although only just of age, he rapidly rose in fame and corresponding fortune.

In 1822 he went to South America in the 'Anna Robertson,' and was in command of that vessel when she was taken up as a transport for troops for the Burmese war. In the course of the war in 1824 he assisted at the capture of Cheduba, in a vessel of his own design and construction, and thenceforth he devoted himself to the study of the local peculiarities and of the navigation of the rivers of India, and to meeting by nautical engineering the wants of the several cases. It was admitted that his vessels were eminently successful, and few of them suffered even from cyclones.

In 1828 he built the 'Forbes,' of 120 H.P., the first steamer that went to China in 1830, towing a clipper. In 1831 he built the 'Water Witch,' and made twelve voyages in her from India to China, the vessel being owned by himself and two merchants. They charged no commission, but early in 1837 divided £100,000. This vessel was remarkable for beauty and speed; she is still efficient, and is known by every one who visits China and the adjacent coasts. In 1837 he built the 'Ariel,' and formed the Clipper Fund, £50,000 being subscribed by three mercantile firms and two captains. On his return to England in the same year he was called on by Lord William Bentinck to give evidence before a Committee of the House of Commons on steam communication in India. In conjunction with his lordship and the late Mr. Auber he assisted in forming the East India Steam Navigation Company, and soon afterwards the Assam Company, having about that time designed the river steamer 'Assam,' 140 feet by 27 feet, 100 H.P., and the ocean steamer 'Comprehensive,' of 2,000 tons, and 600 H.P., and 16 feet draught. In 1839 he designed the 'Andrew Henderson' and the 'Dwarkanauth Tagore' for the Steam Tug Association, and established the 'Assam' on the Brahmaputra in 1841. The 'Sir James Melvill' (now the 'Nepaul'), also on his design, was lately at work between Kooshtee and Debroghur.

In 1840 he took the command of the steamer 'India,' built by Scott, Sinclair, and Co., the first steamer that went round the Cape. He conveyed then the first mails between Calcutta and Suez,

bearing the important news of the massacre at Cabul, and other disasters of the Affghan war. These despatches he forwarded home from Suez, anticipating the regular mails, and enabling troops to be sent many weeks sooner than they would have been. For this important service he received bare thanks, but lost upwards of ten thousand pounds.

Always with the same earnest desire for the establishment of cheap and easy river transit in India, he instituted a system of measurement for tonnage, and a record of vessels and engines, which, as a valuable improvement, was brought before the Board of Trade. He applied his mind and time energetically to this subject, and spent large sums in attempts to obtain the greatest carrying power with high speed at the smallest cost and lightest draught. He built a vessel, the 'Assam Nautilus,' purposely for experiment, and succeeded in obtaining easily the means of proving the relative efficiency of vessels, and the cost per ton per mile as a criterion of cheap transit, so important on the Indian rivers. In this vessel was placed his patent bow and stern rudder, which greatly reduced the resistance, and increased the facility of steering and turning. This vessel could thread the most tortuous rivers, and turn in an incredibly short time. He was bitterly disappointed at not seeing this improvement at once carried out; he spent a very large sum in bringing it to perfection, and always felt convinced the Orissa famine could have been prevented, had some vessels on this plan been ready to carry rice up the difficult rivers. Eventually, shortly before his death in 1868, the 'Assam Nautilus' was sold, taken to South America, and has already realised a large fortune for her owner. The necessity for parting with this vessel, not to the Indian government, as he desired, but to a private individual, was too much for his health, already enfeebled by great anxiety and constant disappointment. He never recovered the blow, and passed away after more mental than bodily suffering on the 20th of February, 1868. The India Board were on the point of recognising his services by the award of a pension, but this he did not live to have the gratification of knowing.

He was a man of genial manners and a truly kind heart; he was universally esteemed and beloved where he was known; and by all with whom he came in contact his good, gentlemanly qualities and highly honourable character were freely admitted.

He was fond of engineering pursuits, and he invested his money too freely in such large affairs as the Birkenhead Docks, &c., which were unproductive. He had talent to make a large fortune, but not selfishness enough to keep it. The kindest tributes to his memory came from high quarters as well as sorrowing friends.

He joined the Institution of Civil Engineers as an Associate in

the year 1840, and was very constantly at its Meetings, when he frequently took part in the discussions, and he was also a regular attendant at the yearly Meetings of the British Association.

Mr. EDWARD LOYSEL, son and grandson of "Ingénieurs-en-chef des Ponts et Chaussées," was born in the year 1816, at Varnes (Morbihan), France. In the years 1838-40 he was Professor of Natural Philosophy and of Industrial Mechanics at the Athénée Municipal de Marseilles, where his lectures obtained a great success, being attended by upwards of five hundred workmen, foremen, and others. He was the author of several educational treatises, as "Leçons d'Arithmétique Pure et Commerciale," "Manuel Arithmétique des Arts et Métiers," &c., written principally for mechanics, as well as of several publications of general economy. He was likewise the inventor of numerous articles of domestic utility, and of modes of making extracts from vegetable substances, such as dye-woods, beet-root, malt and hops, medicinal substances, &c., which he carried out on a large scale.

He came to reside in England in the year 1844, and became a naturalized British subject about the year 1849. He was elected an Associate of the Institution of Civil Engineers in March, 1855, having in the previous session furnished some particulars of his hydrostatic percolator[1] for extracting colouring matters from dye-woods, and also for obtaining infusions or extracts of vegetable substances for medicinal or other purposes. His decease occurred on the 29th of September, 1865.

Mr. FREDERIC CORNELL REYNOLDS was born at Wormsley Grange, Herefordshire, on the 18th of December, 1836, and was chiefly educated at the City of London School. His first professional employment was at the Butterley Iron Works, Derbyshire, under his brother, Mr. Edward Reynolds, where he remained two years, commencing in 1853. From 1855 until his death he was engaged under Mr. F. J. Bramwell (M. Inst. C.E.), for the greater part of the time as principal assistant. He died in London on the 1st of September, 1868, from the effects of injuries received during the disastrous hurricane that occurred on the 29th of October, 1867, at the Island of St. Thomas, in the West Indies, where he was occupied in superintending the raising of the floating dock, which had been sunk through the disarrangement of some of the sluice-valves in the bottom. He was elected an Associate of the Institution of Civil Engineers on the 9th of January, 1866, and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., p. 416.

became a Member of the Institution of Mechanical Engineers in the same year. He had excellent professional abilities, while his agreeable manner, and the versatility of his talents rendered him a general favourite.

Dr. THOMAS RICHARDSON, Ph.D., M.A. (Durham), F.R.S. L. and E., &c., was born in Newcastle about the year 1817. His preliminary education was received in that town, but at a comparatively early age he proceeded to the University of Glasgow, where he worked in the laboratory of Dr. Thomson. He then entered the Giessen Laboratory, and studied organic chemistry under Liebig. Thence he went to Paris, where he spent some time working, it is believed, under Pelouze. Returning to Newcastle, he commenced professional practice, but soon became connected with manufacturing chemistry. For some time he was largely interested in lead-works, and introduced the "improving" process for Spanish hard leads, as well as a modification of the 'Economico' furnace. Towards 1852 he devoted himself especially to the manufacture of artificial manure, and at the time of his death was managing partner of the Monkton Manure Company. He held for a long time the joint chair of chemistry in the College of Medicine, at Newcastle-upon-Tyne, and in 1859 succeeded Dr. Johnston in the readership in chemistry of the University of Durham. His speciality throughout life was Chemical Technology and he is best known to chemists by his share in the translation (which really amounted to the writing of a new work) of Knapp's Chemical Technology. He was also the author of various Papers on the application of Chemistry to Manufactures. To Engineers, however, he is, perhaps, better known from his practical investigations of the economical combustion of fuel under steam-boilers, undertaken originally on behalf of the North Country Steam Coal Association, in conjunction with Sir W. S. Armstrong, M. Inst. C.E, and Mr. J. A. Longridge, M. Inst. C.E.: these experiments were largely extended on the Northern and Welsh coals at the Keyham dockyard, and demonstrated several new facts of importance. At the time of his death, which occurred on the 10th of July, 1867, in the fifty-first year of his age, he had just concluded an elaborate examination, since published, in company with Mr. L. E. Fletcher, Assoc. Inst. C.E., of the Lancashire and Cheshire coal. He had only been elected an Associate of the Institution on the 3rd May, 1864, and had therefore belonged to the Society too short a time to become generally known to the members by active participation in its proceedings.

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